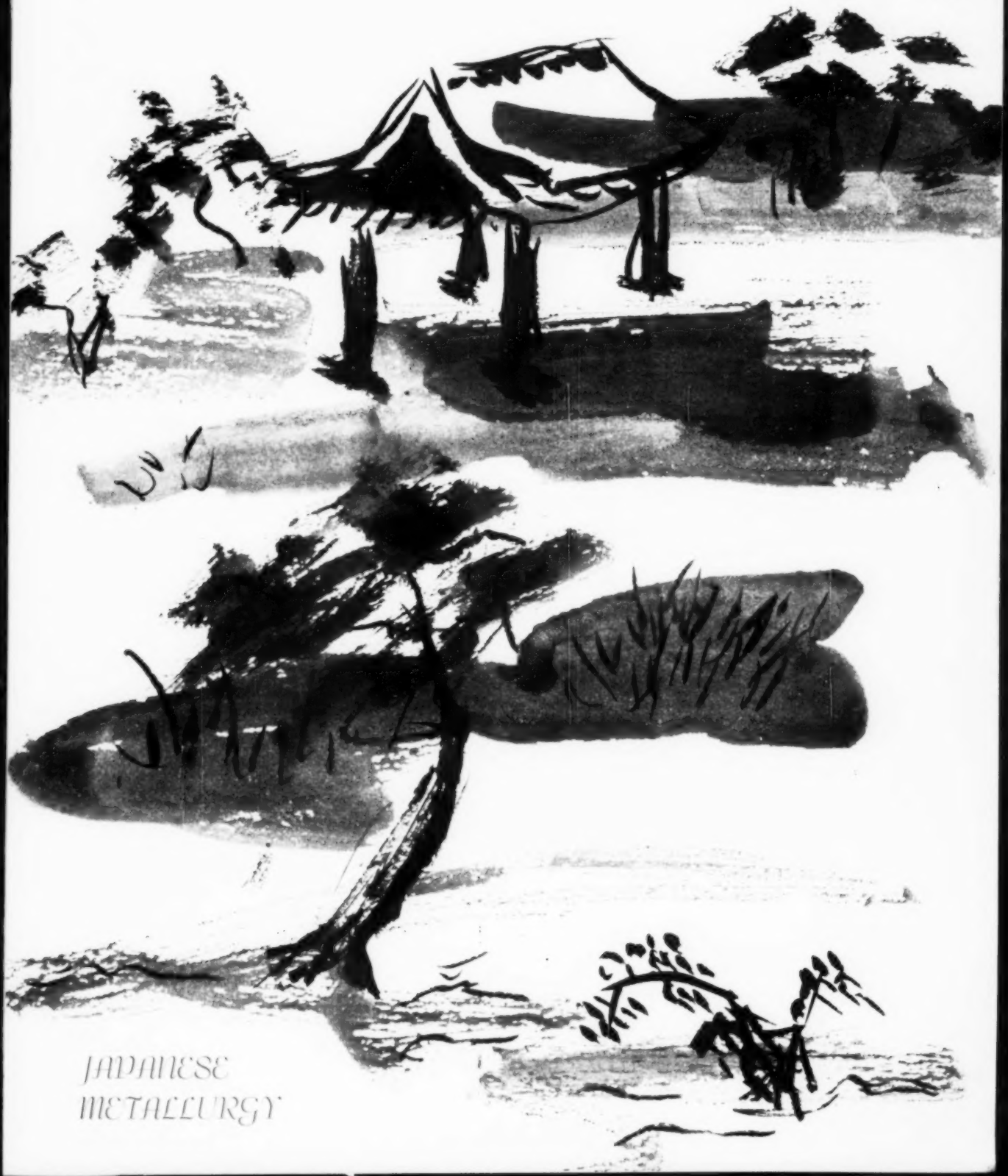
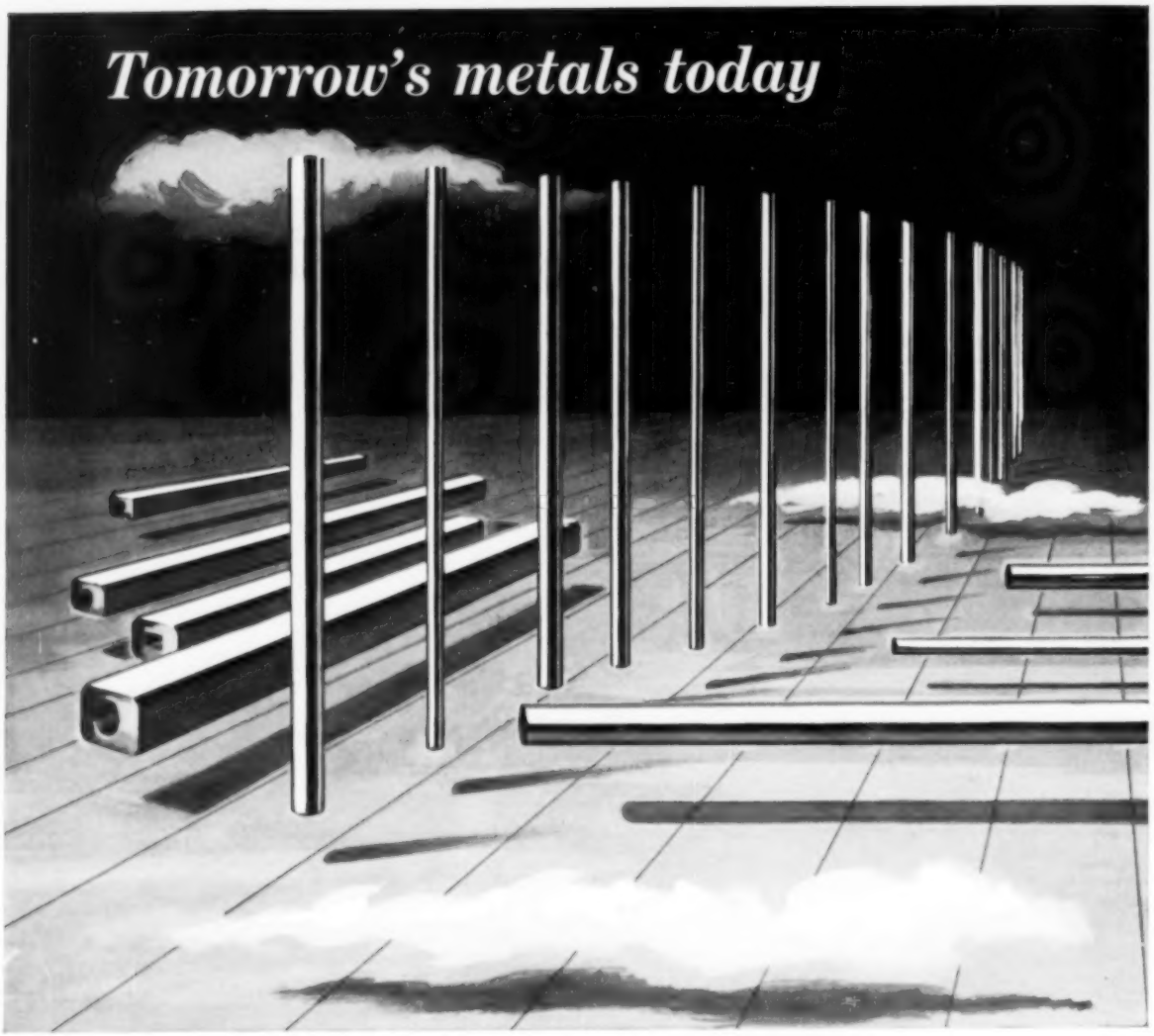
JOURNAL OF

METALS

MARCH 1959





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JOURNAL OF

METALS

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(*Continued on page 152*)

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Argonne National Laboratory has several positions open for Physical Metallurgists or Solid State Scientists to engage in basic and fundamental research on the properties and structures of reactor metals and ceramic materials. Areas of research include metal alloy theory, crystal structures, crystal imperfections, diffusion, irradiation effects in single crystals, plastic deformation, and high temperature properties of ceramics. Excellent facilities available for x-ray and neutron diffraction, optical and electron microscopy, magnetic measurements, and irradiation.

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education

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• **New York University's College of Engineering** will present four summer programs during the summer of 1959 intended primarily for practicing engineers. A one week course will be given for the first time, in *Thermoelectric Materials* starting June 15th. In addition, a similiar one week course in *Ductile Iron* is planned for June 29th. Both courses will consist of lectures and panel discussions by experts from industry and research labs. On June 1st and 2nd, and on September 14th and 15th, the department will present two-day conferences on *Vacuum Metallurgy* and *Titanium Metallurgy*, respectively.

• **Conference Board of Associated Research Councils, Committee on International Exchange of Persons** is offering an expanded exchange program to Latin America, and research fellowships to member countries of the South-East Asia Treaty Organization (SEATO), and the North Atlantic Treaty Organization (NATO) countries.

Persons interested in applying for the Latin American grants should be fluent in Spanish and interested in short-term lecturing during the summer, or fall, of 1959. There are opportunities for lecturing in American literature and civilization, archeology, chemistry, economics, education, English composition, international law and physics. Additional requests may be received during tthe coming months in virtually any field. Inquiries from universities wishing to invite Latin American scholars to the US are welcome. Fulbright and Smith-Mundt Act awards are available.

Those interested in the research fellowships offered in SEATO countries must be a national of a member state and undertake his research in SEATO countries within the

(*Continued on page 152*)

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Education

(*Continued from page 150*)

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All inquiries should be made to the *Conference Board of Associated Research Councils, Committee on International Exchange of Persons, 2101 Constitution Ave., Washington 25, D. C.* Applications for NATO fellowships should be submitted no later than March 15th.

Personnel

(*Continued from page 148*)

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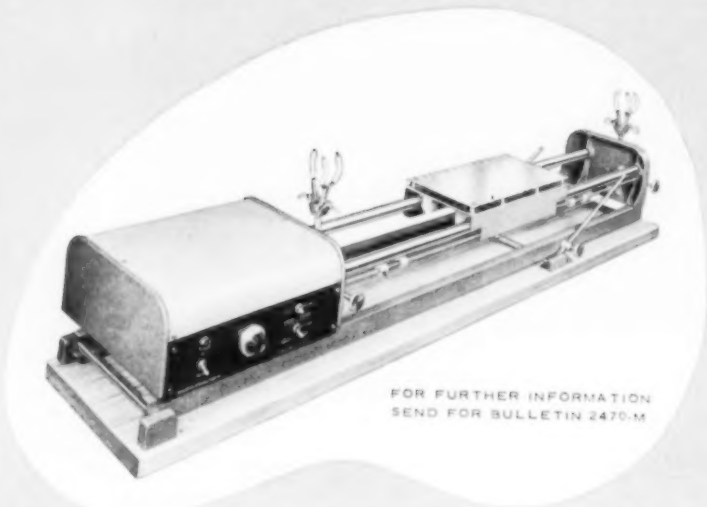

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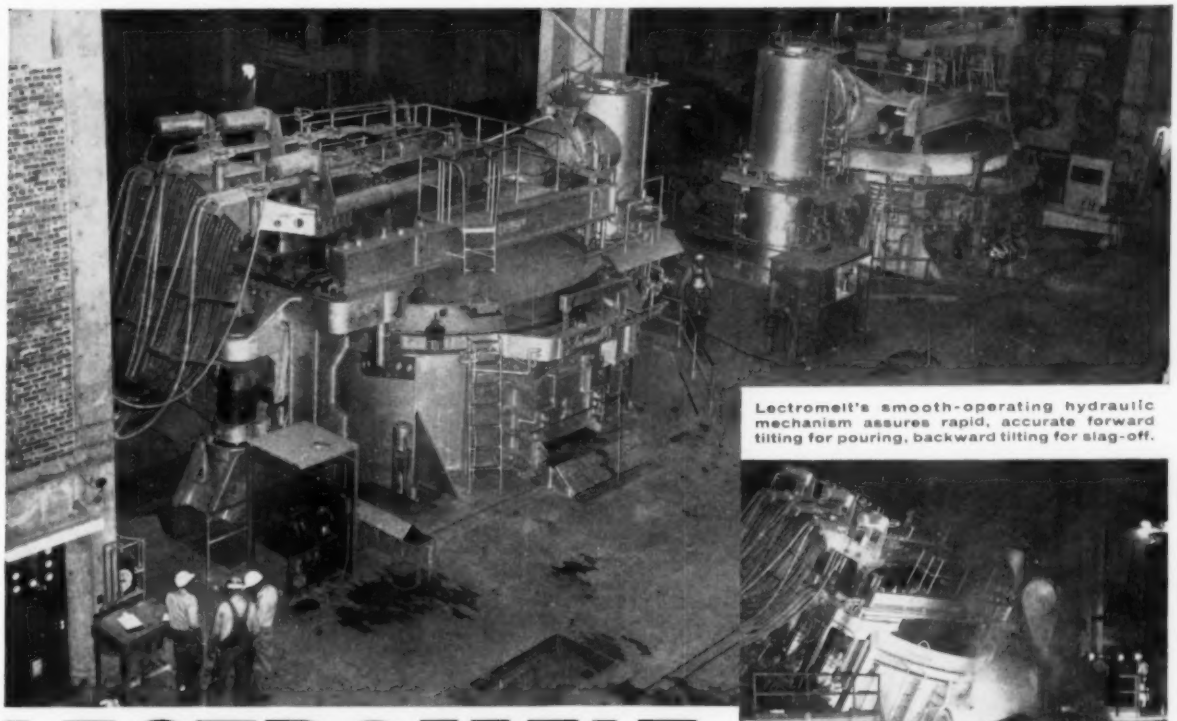

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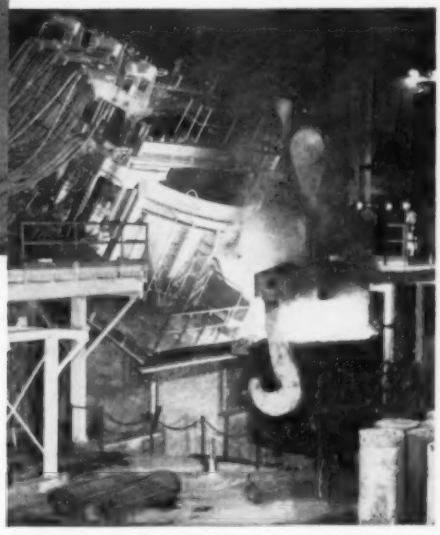

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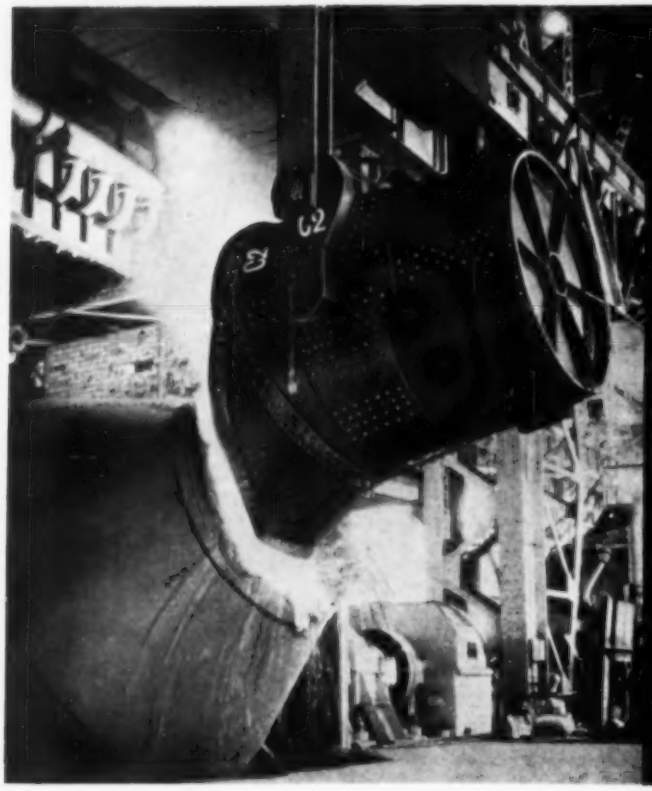

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EDITORIAL

ANNUAL REPORT of the Secretary of The Metallurgical Society of AIME

by R. W. Shearman
(Abstracted from the Complete Report)

THE year 1958 was devoted in large measure to implementing plans made in 1957 following reorganization of the Institute, and to consolidating the changes begun during the preceeding year. A new publication, TRANSACTIONS OF THE METALLURGICAL SOCIETY OF AIME, was launched in February 1958, on a bi-monthly basis. JOURNAL OF METALS sported a *new look* with increased emphasis on professionalism and on general articles of a review nature. With the beginning of 1958, the editorial staff of JOURNAL OF METALS was completely separated from the staff of MINING ENGINEERING, and administratively was made a part of the Society Secretary's office. During the early part of 1958, a highly qualified educator in metallurgical science was engaged as Editor of TRANSACTIONS.

The Society staff was augmented in order to handle more adequately the ever increasing work load. At mid-year, an Assistant Secretary was hired by the Society, and given the immediate assignment of laying the groundwork of a membership campaign that would result, in months to come, in increased membership and increased income for the Society.

During 1958, in line with the plans outlined for reorganization of the Institute, a study was made as to the best way of handling advertising for the Society journals. After thorough study, arrangements were made for the solicitation of advertising in JOURNAL OF METALS by an experienced agency serving as advertising representatives to well-recognized publications.

Operationally, 1958 was marked by continued concentration on *Technical Conferences* and *Regional Meetings* as a means of reaching an increased number of AIME members. Membership experienced a moderate growth. Most pleasing to the officers and staff was the acceptance of the new publication, TRANSACTIONS OF THE METALLURGICAL SOCIETY OF AIME, with subscription revenues exceeding the estimates. This in large measure contributed to the financial stability of the Society, and completion of the year comfortably in black ink.

Budget

At the close of books on Dec. 31, 1958, *Income over Expenses* stood at $591.87. Although a relatively small surplus is shown, it should be noted that reliance on the Metals Research Publications Fund was reduced from a figure of $36,576.00 in 1957 (576 pages of TRANSACTIONS papers in four supplements of JOURNAL OF METALS) to $15,000.00 in 1958 (886 pages of TRANSACTIONS in six issues of TRANSACTIONS OF THE METALLURGICAL SOCIETY OF AIME). The lesser amount taken from the Metals Research Publications Fund is due to subscriptions received for TRANSACTIONS in 1958 in the amount of $20,363.39.

In drawing up the budget for 1959, income and expenses for TRANSACTIONS OF THE METALLURGICAL SOCIETY OF AIME have been set apart from the overall Society budget, as income is almost completely from the Metals Research Publication Fund and the sale of subscriptions.

Contributions received by the Publications Fund during 1958 totaled $16,200.00. To date, contributions have been received from 84 organizations. The status of the Fund as of Dec. 31, 1958, is shown below:

Income

Contributions Received During 1958:	$ 16,200.00
Contributions Received: During 1954-57:	144,675.00
Interest Accrued:	6,015.74
Transferred from Metallurgical Society Operating Fund:	1,362.46
Total Income:	$168,253.20

THE METALLURGICAL SOCIETY OF AIME

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W. R. Hibbard, Jr. — Past-President
C. C. Long — Vice President
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Expenses	
Publication of Metals Transaction Papers, 1958:	$15,000.00
Publication of Metals Transactions Papers 1954-57:	106,696.96
Total Expenses:	$121,696.96
Balance as of Dec. 31, 1958:	$46.556.24

Publication of Transactions papers

Summarized below are data on TRANSACTIONS papers published during 1958 by the three Divisions of The Metallurgical Society.

Division	No. of Papers & Notes	Pages
Extractive Metallurgy	21	107.0
Institute of Metals	169	696.5
Iron and Steel	15	82.5
Total Metallurgical Society	205	886.0

The total of 886 pages published in 1958 is greater by 54 than the 832 pages published in 1957. (In addition, in 1958, 10 pages were devoted to title pages and editorials.) During the first of 1958, the first five issues of TRANSACTIONS contained 144 pages each. Because of increasing backlog of papers, 32 pages were added to the final issue of the year, and it is anticipated that in 1959 each of the six issues of TRANSACTIONS will contain 176 pages, or a total of 1056 pages for the year.

During 1958, Volume 209 (Metallurgical Society) of AIME TRANSACTIONS was published.

Other publications

The Institute of Metals Division published Volume V of the series on *Nuclear Metallurgy*. This volume comprised ten papers presented at a symposium on the Fabrication of Fuel Elements during the Fall Meeting of The Metallurgical Society in November 1958.

The Institute of Metals Division also published during the year a Proceedings volume on the First Reactive Metals Conference held in Buffalo, 1956. A third book published during 1958 by IMD is entitled *Angles Between Planes in Cubic Crystals*.

Within the Iron and Steel Division, annual volumes of conference Proceedings were published by the National Open Hearth Steel Committee, the Electric Furnace Steel Committee, and the Blast Furnace, Coke Oven, and Raw Materials Committee.

The Board of Directors of The Metallurgical Society, in an endeavor to establish a uniform publications procedure for Proceedings of conferences held under the auspices of the Society, its Divisions, and technical committees, approved adoption of an arrangement with a commercial publisher for publication of these books on a royalty basis. The first volumes under this procedure will be published in 1959.

Division activities

During 1958 all three Divisions reviewed their bylaws and revised them to be in accord with the bylaws of The Metallurgical Society of AIME.

The Extractive Metallurgy Division very carefully studied its organization. As a result it established new committees to cover such fields as *High Temperature Materials Uranium, Rare Earths*, and *Minor Metals, Light Metals*, and *Nuclear Fuel Reprocessing*. Committees are arranged both on commodity and a functional basis, a total of 11.

The Institute of Metals Division, through its Committee on Scope of Technical Committees, has maintained a continuous review of the scope of activities of IMD technical committees. As a result, each of its 18 technical committees has clearly defined its scope and objectives.

The Iron and Steel Division is also planning to appoint a *Scope Committee*. In the meantime, several changes have taken place, the most significant being a change in name of the *Electric Furnace Steel Committee* to *Electric Furnace Committee*. This committee is now undertaking technical programs on the use of the electric-arc furnace for non-steel products. Its scope of activities includes the production of ferro-alloys, calcium carbide, special abrasives, and refractories.

It should also be noted that The Metallurgical Society is also studying the overall technical committee structure, and is considering the possibility of Society committees in these areas: 1) marketing and economics in metals industries, 2) process design and control, and 3) refractories.

Committees

The IMD Corrosion Resistant Metals Committee has begun an active program and has scheduled a conference on *Physical Metallurgy of Stress Corrosion Fracture*, which will be held in Pittsburgh on April 2 to 3, 1959. Proceedings of this conference will be published.

Through the cooperative efforts of the ISD Physical Chemistry of Steelmaking Committee, the EMD Physical Chemistry of Extractive Metallurgy Committee, and the IMD Committee on Melting and Casting, The Metallurgical Society has scheduled an International Symposium on the Physical Chemistry of Process Metallurgy, to be held in Pittsburgh, April 27 to 30, 1959.

The IMD Semiconductors Committee will hold its first symposium in Boston, Aug. 31 through Sept. 2, 1959.

The ISD Mechanical Working Committee planned a program on *Factors Affecting Shape and Surface Texture of Hot and Cold Rolled Products* and *Continuous Heat Treatment of Flat Rolled Products*, which was held in Chicago, Jan. 21, 1959.

New section

During 1958 the Hudson Mohawk Section of AIME was established to serve metals men in the Schenectady-Albany-Troy area of New York State.

Acknowledgment

Acknowledgment is gratefully made to the many members of AIME who served so faithfully as officers or as members of committees. Without their loyal help, their advise, their devotion to AIME, the work of The Metallurgical Society could not be carried on.

Gratitude is also expressed to the industrial organizations that assisted The Metallurgical Society in the solicitations that were made for the Metals Research Publications Fund.

Respectfully submitted
R. W. Shearman, Secretary
The Metallurgical Society of AIME

letters to the editor

Columbium-treated steels

I read with great interest in your December issue the article titled *Columbium-treated Steels—low-cost, high-strength*. You are to be complimented on publicizing this new commercial application of columbium. We at Union Carbide Metals Co., (formerly Electro Metallurgical Co.) div. of Union Carbide Corp., believe that, columbium-treated, mild-carbon steels have a great future for low-cost, high-strength structural applications. I have already congratulated Great Lakes Steel Co. on bringing this development to commercial fruition and it occurred to me that you might be interested in amplifying your editorial statement with some more background information.

The interest of our Company in columbium additions to both plain carbon and low-alloy constructional steels goes back a good many years, as the dates of four patents issued to Becket and Franks indicate. The first three of these cover columbium additions to constructional alloy steels for grain refinement, and the fourth covers columbium additions to carbon steel. The patents are dated: May 6, 1939 (two); March 19, 1940; and Dec. 2, 1941.

As you can see from these patents, Union Carbide Metals' work in the field of columbium additions probably antedates most other investigations. Commercial development of these patents was delayed largely by long-standing Government restrictions on the use of columbium. These restrictions have been lifted and, with new ore sources and refining techniques, Columbium is now in ample supply.

Russell Franks, Manager
Marketing Research Div.
Union Carbide Metals Co.

Meeting programs

I was rather amazed to see the very brief outline of the AIME, Metallurgical Society annual meeting, San Francisco, Feb. 15 to 19, 1959, in JOURNAL OF METALS, December.

It is difficult to sell management on spending money for someone to attend your meeting. Can you send me a more detailed program.

M. A. Scheil, Director
Metallurgical Research
A. O. Smith Corporation

[The above letter came to JOURNAL OF METALS through its initial recipient, Dr. J. H. Hollomon, chairman of the JOURNAL OF METALS Advisory subcommittee. Dr. Hollomon adds "Why is it that the technical program is not published in more detail?"

We are in complete agreement with you regarding the late appearance of the technical program for the 1959 Annual Meeting, and we fully understand the difficulties which management may encounter in regard to deciding whether or not to send its personnel.

JOURNAL OF METALS publishes technical programs just as soon as they have been finalized by program chairmen and passed along to us. Thus, when the December issue went to press in the second week of November, we published (p. 817) all information then available. This consisted only of the general subject for discussion at each of the technical sessions.

Yours is not the first complaint about the matter (see Letters to the Editor, February 1959), and we can only say that we make every effort to get information on technical programs to our readers as soon as possible. Unfortunately, we cannot disseminate information which we have not received. Thus, we think your voice should be added to ours in urging program chairmen to send their programs to this office at an early date. **Ed.**]

RESEARCH METALLURGISTS

The J&L Research Division wishes to add to its staff in 1959 several professional metallurgists, to broaden the scope of the Corporation's research programs in carbon and stainless steels.

Of specific interest are physical metallurgists (Ph.D., or M.S. with related research experience) to conduct projects in high-temperature materials, alloy development, corrosion, general applied physical and mechanical metallurgy.

Several openings exist also for recent B.S. graduates, in the fields described above and in projects dealing with steelmaking process analysis and development. For the B.S. graduate interested in a permanent research career, Pittsburgh offers unmatched opportunity for continued education at the graduate level.

J&L is fourth-largest in the United States steel industry, making a wide variety of carbon and stainless steel products. The Research Division is located in modern facilities in suburban Pittsburgh.

J&L STEEL

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For fundamental and development studies in metallurgical field with new research group in established company, leaders in chemical, petroleum and metallurgical plant design and process field.

PhD or MS preferred, with experience in the metallurgical field, and interest or experience with iron ore reduction and beneficiation.

All inquiries in strict confidence. Please write complete details including salary requirements.

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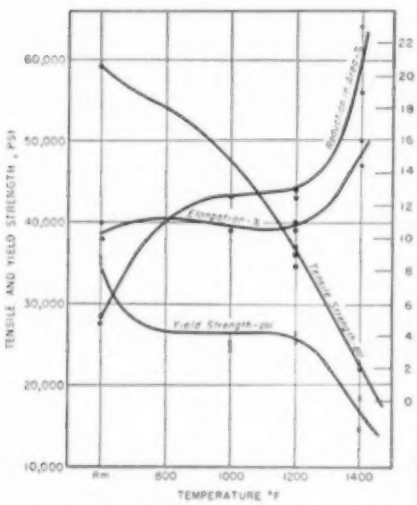
Ni-Resist* ductile irons are a new family of versatile high-alloy cast irons developed by Inco. Containing 18 to 36% Nickel, they provide the same high order of corrosion and heat resistance given by Ni-Resist flake graphite iron...plus high levels of strength and ductility.

There are several types of Ni-Resist ductile iron. Each one combines a useful array of engineering properties.

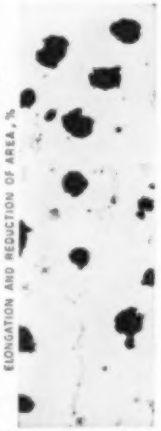
Strength Ni-Resist ductile irons provide tensile strengths of 55,000 to 80,000 psi, yield strengths of 30,000 to 44,000 psi. See graph of properties below.

Toughness Ni-Resist ductile irons give elongations of 4 to 40%, together with good impact resistance. The photomicrograph below shows why – spheroidal graphite particles allow formation of an austenitic matrix. This nickel alloy matrix develops full ductility and strength . . . keeps these properties at low temperatures.

Corrosion resistance Ni-Resist ductile irons safely handle hundreds of corrosives. Under most conditions – with acids, alkalies and salts – their performance is far superior to both cast iron and steel, helping you reduce maintenance costs.



High temperature tensile properties of Type D-2 Ni-Resist ductile iron.



Ni-Resist ductile microstructure X 100. Spheroidal graphite particles allow the metal to develop the full strength and toughness of the high alloy austenitic matrix.

High temperature properties Ni-Resist ductile irons form a tightly adhering scale at elevated temperatures, greatly reducing further oxidation. They resist heat effects up to 1400° F and higher, have excellent thermal shock resistance. From 1100° to 1300° F, Type D-2 has stress rupture properties equal to those of cast HF stainless steel.

Wear resistance Ni-Resist ductile irons have a work hardening austenitic matrix. Graphite particles provide dry lubrication. Both properties work together to resist wear and galling over a wide temperature range.

Erosion resistance Ni-Resist ductile irons work well in wet steam, brine or salt slurries, and high velocity liquids. Their high strength and resistance to cavitation-erosion mean long service life for pump parts.

Controlled expansion Ni-Resist ductile irons have thermal expansivities from about 2.5 up to 10.4 millionths per degree F. You can match them with steels, cast irons, Nickel, Monel* alloy...with aluminum, copper, bronze and stainless steel.

Non-Magnetic properties Ni-Resist ductile irons, Types D-2 and D-2C, are non-magnetic and therefore useful where excessive heat and power losses must be avoided.

Machinability Ni-Resist ductile irons machine as well as common pressure-type gray iron, thanks to the presence of graphite in their structure.

Fluidity in casting Ni-Resist ductile irons have good flowing qualities and permit the making of intricate designs.

These are only the highlights. You can get *all* the facts on this versatile new family of metals by asking us for "Engineering Properties of Ni-Resist Ductile Irons." This 28-page booklet details engineering properties and commercial applications with numerous photos, tables, and graphs . . . gives you the information you need to decide how Ni-Resist ductile irons can help you. You'll also get "Buyers' Guide for Ni-Resist and Ni-Resist Ductile Iron Castings", listing foundries authorized to produce them.

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THE INTERNATIONAL NICKEL COMPANY, INC.

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NI-RESIST DUCTILE IRONS

NICKEL ALLOYED IRONS PERFORM BETTER LONGER

Foamed metal developed

Foamed metal that resembles a petrified sponge and is nine times lighter than solid metal, has been developed by General Electric's Flight Propulsion Laboratory in Cincinnati. Although the technique is still in the development stage, nickel, copper, and cast iron have been foamed successfully. Laboratory experiments and actual engine tests have demonstrated the value of the foamed metals for use as rubbing seals in high-temperature areas of jet engines. The possibility of using foamed copper in large electrical installations has been conceived. Foamed metal can be molded into practically any desired shape during the baking process, and may be machined with conventional tools.

Super-fine metal powders

A newly discovered method for producing ultra-fine metal powders with particles one-millionth of an inch in diameter (one thousand times smaller than previously obtainable) may lead to new metallurgical applications. Aluminum, iron, and nickel powders have been developed by National Research Corp.'s staff; copper, silver, gold, cobalt, manganese, lead, zinc, alkaline earths, and a number of other metals appear to be likely candidates. Super-fine powders may open up short-cuts to new, exact composition alloys having superior physical properties over the best known today.

Columbium extrusions

Commercial production of extrusions made from columbium has been announced by Wolverine Tube, div. of Calumet & Hecla Inc. The development was made with the co-operation of Wah Chang Corp., which supplied ingots and basic data for the tests.

Molybdenum breakthrough

A possible important breakthrough in molybdenum casting has been announced by the US Bureau of Mines. The method involves casting under special conditions with the reported use of copper and carbon molds, and special cooling. It is probably the first time that a hollow form (which can be used for nozzles in solid fuel propellant nozzles) of the metal has been cast directly.

Yttrium developed

Difficult problems in the design of atomic reactors and missiles may be solved by improvement of yttrium purity. The US Dept. of Interior says US Bureau of Mines metallurgists have succeeded in transforming the metal into a pliant, easily fabricated form. The high-purity yttrium made by the Albany, Ore. Lab., contains about 0.02 pct O_2, thereby increasing ductility. The metal has a relatively high melting point of 2825°F, and relatively low thermonuclear cross section.

Pelletizing unit planned

Ford Motor Co. and The Cleveland-Cliffs Iron Co. have announced jointly a multimillion dollar program to expand facilities for mining and concentrating iron ores in Michigan's Upper Peninsula. The program will double production capacity of Humboldt Mining Co. by including a second concentrating unit. Outstanding feature will be the installation of pelletizing equipment to produce high-grade, marble-size pellets from the concentrate. Humboldt's capacity will, thus, be increased to about 640,000 tons of pellets annually by mid-1960.

CONDENSED PROGRAM

Blast Furnace, Coke Oven, and Raw Materials Conference

Sunday, April 5

3-9 pm **Registration**

Monday, April 6

8 am-5 pm **Registration**

9:30 am **Raw Materials and Miscellaneous Session**
Welcoming remarks; design and operation of a new large sintering plant: United States and England; Meramec ore deposits in Missouri; model blast furnace investigations.

9:30 am **Coal Session**
Automatic bulk density control at Fairless Works; Soviet advances in coal preparation; better coal preparation through better crushing.

2:00 pm **Blast Furnace Theory Session**
Laboratory evaluation of performance characteristics of various types of sinter; blast furnace sinter-related to burdening and charging; experimental smelting of a siliceous iron ore; latest trends in elevated pressure blast furnace operation: United States and USSR.

2:00 pm **Coke Session**
Design, construction, and operation of large Soviet coke ovens; Canadian coals in ferrous metallurgy; methods of banking coke ovens; production and use of ferro coke.

Tuesday, April 7

8 am-5 pm **Registration**

9:30 am **Manufactured Blast Furnace Burdens Session**
Sinter: Bethlehem Steel Co.; pellets: Bethlehem Steel Co; flux sinter: Japan, England, and USSR; mixing and conditioning of sinter plant feed.

9:30 am **Coal Chemicals Session**
Application of tar pressure decantation for dehydration and chloride reduction; problem of coke oven ammonia recovery; world market for coal chemicals; chemicals in coal tar.

12:30 pm **Luncheon Meeting**
Everyone attending the Blast Furnace, Coke Oven, and Raw Materials sessions is invited to attend this luncheon and annual business meeting.

2:00 pm **Joint Blast Furnace and Coke Oven Session**
Quo vadis: blast furnace; a new electric direct reduction process producing steel or pig iron.

6:30 pm **Reception**

7:00 pm **Annual Fellowship Dinner**

Wednesday, April 8

8 am-4 pm **Registration**
Plant trips, see below.

Note: Participation by Soviet metallurgists expected, but not fully confirmed.

CONDENSED OPEN HEARTH PROGRAM

Sunday, April 5

3-9 pm **Registration**

Monday, April 6

8 am-5 pm **Registration**

9:30 am **General Session**
Welcoming remarks; announcements and reports; *McKune Award* paper.

10:30 am **Basic Operations Session**
Description of Sparrows Point #4 Open Hearth; open-hearth problems with high per cent hot metal charge.

10:30 am **Acid Operations Session**
Use of pig iron substitutes; use of oxygen for complete refining; use of deuterium as a tracer element for hydrogen in steel.

2:00 pm **Operating Metallurgy Session**
Control of chemical composition: a practical program for avoiding off analysis heats; use of capped low carbon steel ingots for drawing quality cold rolled sheet applications: chemically capped ingots, mechanically capped ingots, large rimmed ingots; steel cleanliness: a study of the influence of bath deoxidation on the cleanliness of 1030 steel, review of symposium on quality requirements of super duty steels.

2:00 pm **Refractories Session (I)**
Properties and composition of the various types of basic brick on roofs; design and operating performance of basic sprung roofs; problems encountered with other sections of basic roof furnaces.

Tuesday, April 7

8 am-5 pm **Registration**

9:30 am **Refractories Session (II)**
Evaluation of clinkered dolomite material; gun emplaced silica ganister in the open hearth; improved methods of repairing open hearth furnace roofs; basic open hearth checkers.

9:30 am **Operating and Combustion Session**
New process for bottom blowing with high pressure oxygen; fuel practice at Fontana; international flame radiation committee studies.

2:00 pm **Oxygen Steelmaking Processes Session**
Use of oxygen in steelmaking; oxygen for flame enrichment; oxygen steel making processes.

2:00 pm **Cold Metal and Basic Foundry Session**
Use of prolerized scrap; use of Calderon charger; use of oxygen in cold metal shops; use of iron substitutes.

6:30 pm **Reception**

7:00 pm **Annual Fellowship Dinner**

Wednesday, April 8

8 am-4 pm **Registration**
Plant trips, see below

Important

All operating men, repair and maintenance men, metallurgists, ceramic and refractory engineers, observers, and any others interested in the production of more steel, better steel and cheaper steel and in any of the problems connected with the reduction of iron ore in the blast furnace, are invited to attend. The complete program will be mailed in March, but make plans now to attend this important Conference.

The registration fee for either Conference is ten dollars ($10.00), which includes a copy of the respective PROCEEDINGS when printed. There is no registration fee for students at any of the sessions, unless they desire a copy of the Proceedings. AIME members are entitled to a three dollar ($3.00) reduction in the registration fee upon presentation of their membership card.

Both meetings promise to be extremely interesting and it seems worthwhile to register for both in order to make sure to receive both volumes of Proceedings.

Hotel Reservations

Adequate hotel facilities will be provided at the Sheraton-Jefferson Hotel and other St. Louis hotels. Hotels, however, will not hold blocks of rooms assigned to this meeting after March 29th. Single rooms are limited. Hotel reservation requests should, therefore, be sent directly to the hotel of your choice as soon as possible. Be sure to mention the Blast Furnace or Open Hearth Conference of AIME as well as the time of arrival in making your request.

Plant Trips

Through the courtesy of Granite City Steel Co. and American Steel Foundries, inspection trips have been arranged through their plants on Wednesday, April 8.

Buses will depart from the Sheraton-Jefferson Hotel at 9 a.m. Visitors to Granite City Steel Co. will have the opportunity of visiting either the open hearth departments or the blast furnaces and coke ovens. Following visitation luncheon will be served in the Boulevard Room of the Sheraton-Jefferson Hotel courtesy of Granite City Steel Co., and at the Rose Bowl Restaurant courtesy of American Steel Foundries.

A charge of $3.00 will be made by the National Open Hearth Steel Committee and the Blast Furnace, Coke Oven, and Raw Materials Committee to help defray the expense of plant trips, transportation costs, and other non-technical conference expenses. (*Use of private cars will not be permitted at the plants. Please cooperate by planning to use the special buses.*)

Expanding the Frontiers of Space Technology

Advancement in missile and space technology is highly dependent on metallographic research being conducted at Lockheed today. Special programs include the study of high and low temperature materials, radioactive and toxic materials, pure metals, properties of beryllium and the alloys, and the development of refractory and special-purpose metals, cermets and ceramics.

Studies are also being made of the creep of materials under high temperatures over very short periods – 15 seconds or less; materials testing in hot flow gases; powder metallurgy; metal working and heat treating; high temperature and vacuum techniques; electron bombardment melting; corrosion and gas-metal reactions; gas solubilities in solids; reaction mechanisms at interfaces; impurities and imperfections; deformation; fracture; x-ray and electron diffraction; and diffusion.

Scientists and engineers of outstanding talent and inquiring mind are invited to join us in the nation's most interesting and challenging basic research programs. Write to Research and Development Staff: Dept. C-55, 962 W. El Camino Real, Sunnyvale, California.

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With infinitely variable speed over a wide range it is possible for the operator to select the exact speed desired for the particular sample at hand. The complete speed range is controlled by turning a knob. No cranking is required to change speed, no belts, pulleys or mechanical clutches are used, eliminating the source of most vibration present in other variable speed polishers. The electronic control is accomplished through the use of only one vacuum tube and the complete electronic circuit is mounted on a 4" x 4" panel easily accessible on the outside of the motor.

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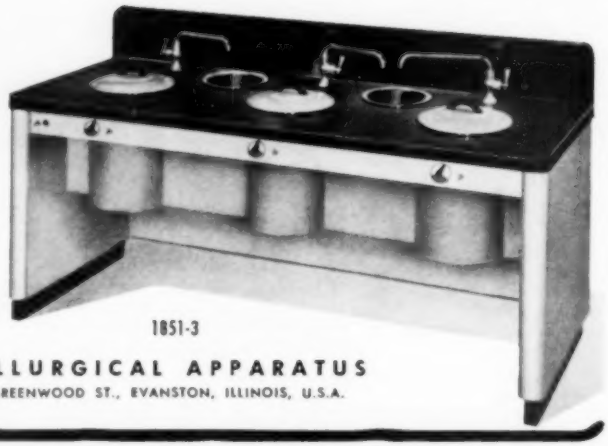

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Degree in metallurgy or ME with good working knowledge of aluminum alloys and MIG and TIG welding. Will be responsible for welding research in aluminum and brass.

Send detailed resume to:

E. R. Patterson, Employment Mgr.
Olin Mathieson Chemical Corporation
New Haven, Connecticut

RESEARCH METALLURGIST— Magnetic Materials. Supervise and conduct research on special purpose alloys such as electrical resistance alloys, controlled modulus alloys and magnetic alloys. 5 to 10 years in field of research and development on soft magnetic materials. M.S. in metallurgy minimum requirement, Ph.D. preferred. W. Pa. location. All replies confidential. Send resume and salary requirement to

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Send confidential resume and salary requirement to:

Mr. J. E. Harris
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IRON AND STEEL INDUSTRY OF JAPAN

Founded at the turn of the century, Japan's steel industry ranks sixth in world production. This article, written exclusively for JOURNAL OF METALS, *tells of this historical development, as well as the current problems and achievements of the Japanese steel industry.*

by Tetsuo Shimamura

JAPAN'S present-day iron and steel industry was founded in 1901 when the Japanese government constructed the Yawata Steel Works in Kyushu. This first plant, the forerunner of Japan's basic industry, was capable of producing 120,000 tons of pig iron and 90,000 tons of steel products annually.

As the Yawata Steel Works developed steadily in those early years, private iron and steel enterprises were founded throughout Japan, and between 1912 and 1925 the rapidly expanding private companies extended their operations into Manchuria and Korea.

After the steel boom of World War I, a series of economic depressions in Japan left many private steel companies seriously weakened. To strengthen the national economy, a proposal was made that all private iron and steel companies be unified around the government's Yawata Steel Works. Action on this proposal was postponed by the army's demand for steel following the Manchurian Incident. A merger of steel companies, nevertheless, was accomplished in 1934 when the Japan Iron & Steel Co. Ltd. (Nippon Seitetsu Kabushiki Kaisha) was established. Important private companies like the Wanishi Iron Works, Kamaishi Iron & Steel Works (from the Mitsui organization), Kenjiho Iron & Steel Works (Mitsubishi), Fuji Steel Works (Shibusawa), Toyo Pig Iron, and Kyushu Steel were unified around the greatly expanded Yawata Steel Works.

The annual production capacity of the newly formed company totalled 2,200,000 tons of pig iron and 2,120,000 tons of steel ingots. These figures, respectively, represented 97 pct and 56 pct of Japan's total capacity and demonstrate the company's pig iron monopoly. The company's annual production capacity subsequently kept pace with increasing

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Open hearth furnaces at the Yawata Works, Yawata Iron and Steel Co., Ltd.

Artificial stars frame the 600-ton blast furnace at Kawasaki works, Nippon Steel & Tube Co. Ltd.

army and civilian needs for steel products, growing by 1943 to 5,260,000 tons of pig iron (35 blast furnaces), and 6,770,000 tons of steel ingots (208 open hearth furnaces).

Postwar developments

The company's monopolistic structure, however, was shattered after World War II. In 1950, in accordance with the Anti-Trust Law based on Allied occupation policy, the Japan Iron & Steel Co. Ltd. was split into two companies, the Yawata Iron & Steel Co. Ltd. (Yawata Seitetsu Kabushiki Kaisha) and Fuji Iron & Steel Co. Ltd. (Fuji Seitetsu K. K.), and reorganized as private enterprises.

The destructive effects of World War II and the loss of foreign sources of raw materials resulted in a postwar decline to 500,000 tons of steel ingots. From this weakened condition the Japanese iron and steel industry recovered rapidly, aided by the world-wide iron and steel boom at the outbreak of the Korean War. Japan ranks sixth, at present, in the production of steel ingots with a 1957 output of 12,570,000 tons. The trend of steel demand in Japan is shown in Table I and Table II.

As a measure to meet increased steel demand through modernization and improvement of equipment, the First Rationalization Plan was initiated in 1951 with a capital investment of about $325 million. Results from this program, as well as from the Second Rationalization Plan of 1956, are now being realized. On the basis of the national economy's present rate of growth, it is predicted that by 1962 at least 18 million metric tons of crude steel will be required.

The Second Rationalization Plan is mainly concerned with (1) expanding existing steelmaking equipment in fully integrated steel producing companies, such as Yawata Iron & Steel Co. and Fuji Iron & Steel Co., and (2) starting fully integrated steelmaking processes by many other companies, such as Kobe Steel Works, Sumitomo Metal Industries Ltd., and Kawasaki Steel Corp.

Table I. Trend of Crude Steel Demand in Japan*
(Unit: 1000 metric tons)

Year	Demand	Year	Demand	Year	Demand
1921	1,540	1940	6,690	1956	9,819
1926	2,573	1945	1,957	1957	12,934
1930	2,689	1950	4,113	1958**	10,175
1935	4,489	1955	7,819	1962	18,135

(Demand equals Production plus Import minus Export)
* Data to 1958 was obtained from *Japan Iron & Steel Statistics*, published by the Japan Iron and Steel Federation; data for 1962 is quoted from "Five-year Program for the Japanese Iron and Steel Industry" by the Economic Planning Board of the Japanese Government.
** The production for December, 1958 is based on provisional figures.

The above plan has succeeded in increasing pig iron production capacity, thus reducing dependence upon scrap iron. This change will affect the pattern of the Japanese steel industry, which was previously dependent on large quantities of imported scrap iron.

As a result of this expansion, the steel industry in 1953 contributed 8.7 pct in additional value and accounted for 6.3 pct of the total number of workers in the whole manufacturing industry. The apparent annual steel consumption per Japanese citizen, according to available statistics, is about 100 kilograms. This compares with 10 kg per capita for other Southeast Asian countries, 600 kg per capita in the US, and 300 to 400 kg per person in European countries. These figures suggest a probable increase in steel demand in Southeast Asia.

In the future the iron and steel demand in the Pacific area, it appears, will grow simultaneously with a gradual shift in the Japanese economic structure toward chemical and heavy industries.

Economic activity has centered up until now on light industries, such as textiles. It seems certain, however, that the gradual movement toward heavy industries will continue. The production level of the mining and engineering industries, it has been estimated, will increase by 60 pct between 1956 and 1962; as a result, the production level of the metal, chemical, and machine industries will rise 82 pct, while light-industry production will increase according to this trend by only 32 pct.

The postwar Japanese iron and steel industry has been extending its markets in Southeast Asia and other world areas, contributing much to Japan's balance in international exchange.

Table II. Japan's Dependence on Imports with Respect to Consumption of Iron Ore* (Unit: 1000 metric tons)

	Consumption of Materials					Dependence on Import (A/B) Pct
Year	Imported Ores (A)	Domestic Ores	Pyrite Cinder	Iron Sand	Total (B)	
1953	4,801	1,181	894	598	7,474	64
1954	4,598	1,183	1,062	564	7,405	62
1955	5,193	1,053	1,277	695	8,218	63
1956	6,572	957	1,192	857	9,578	69
1957	7,549	975	1,250	1,007	10,781	70

* Data from "Seitetsugyo Sanko Shiryo" (annual reference statistics of the Japanese iron and steel industry).

Raw materials

The securing of raw materials is a basic concern of the Japanese iron and steel industry. Japan's mineral resources, including iron ore, are insufficient for her basic industrial needs. Prior to World War II, Japan imported iron ore from China, the Philippines, and Malaya, and high-coking coals from Kailang (North China) and North Sakhalin via comparatively short transportation routes. Japan no longer has access to many of these areas and must import coal from the US and other distant countries.

Ore: Few iron mines in Japan have a known reserve of more than 500,000 tons and, generally speaking, the percentage of iron content in the ore is rather low. Vigorous efforts are being made to find the most efficient uses for other important ferrous materials, such as iron sand and pyrite cinder, as well as for supplementary materials, like open-hearth slag and flue dust.

Thus, denied access to resources on the Asian mainland, Japan must import high-grade ores from distant sources over costly transportation routes. It is of primary importance, therefore, to obtain a continuous supply of ores which are favorable in regard to quantity, quality, and cost. Japan, at present, is importing iron ore from the more neighboring areas of the Philippines, Malaya, and India, as well as from Canada, US, and South America.

Dependence on imported ore, in terms of actual iron content, averaged about 70 pct annually for 1953 to 1957. Recently, however, Japan facilitated the importing of high-grade ores through assistance to less-developed countries with the view in mind of developing them as potential sources of raw materials. With financial assistance from the US, Japan has agreed to develop India's Rour-Kela mine in the hope of obtaining nearly 2 million tons of high-grade ore (average 62 pct Fe) annually during a 10-year period which will commence in 1964. Current political difficulties with mainland China eliminate any chance of obtaining resources from the rich ore fields there, but plans have been projected for developing mines in Australia, Chile, and Venezuela.

Most Japanese iron works are on the sea coast, avoiding the high cost of land transportation. Considering this and the above factors, it can be seen that Japan's position is not necessarily unfavorable when compared with other countries having low-grade domestic ores.

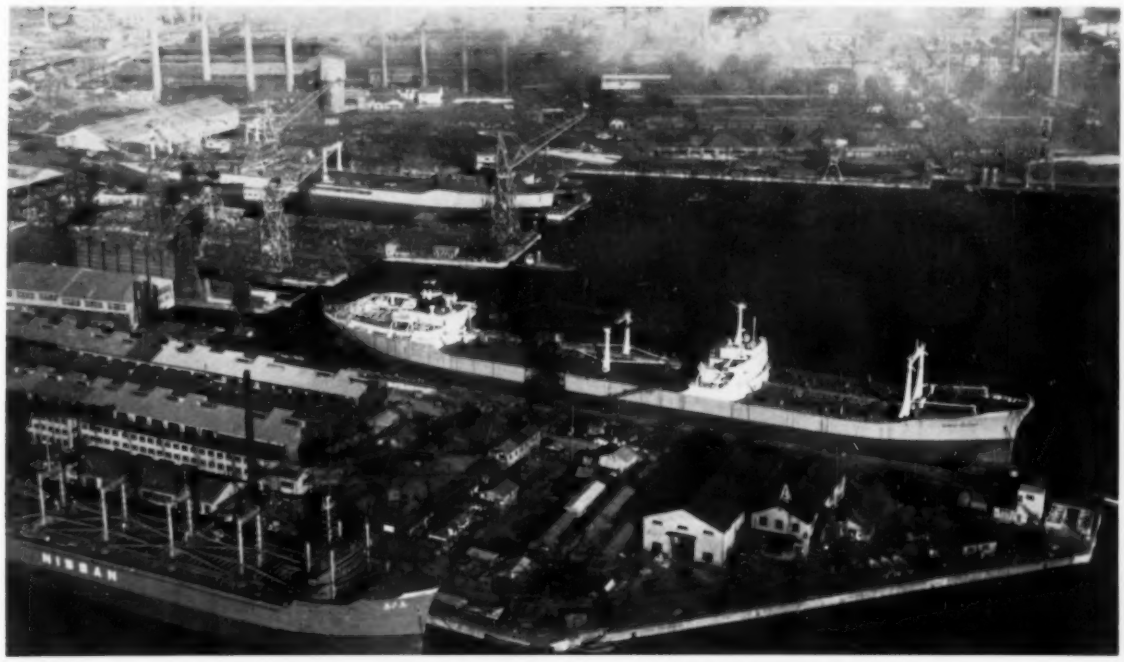
The production of domestic ferrous materials, including iron sand and pyrite cinder, will increase, it has been predicted, from 4.5 million tons in 1956 to 6.9 million tons by 1962, while iron ore imports for the same period will surge from 7 million to 15 million tons. This prediction brings into prominence the need for securing stable supply sources for iron ore.

Another problem now being studied is the instability in iron and steel prices caused by fluctuations in the overseas freight rates. As ameliorating measures to stabilize steel prices, and at the same time to reduce freight cost per unit ton, five 15,000-ton ore carriers are under construction, and a *super* 60,000-ton ore carrier has been proposed.

Coal: In comparison with iron ore resources, Japan's coal reserves are fairly abundant, having been estimated at 15.5 billion tons (including 10.1 billion tons of anthracite). Most of this supply, however, consists of low-coking coal, thus making it necessary to import the greater portion of high-coking coal.

During the past few years, research has concentrated on making the fullest possible use of Japanese coal resources. Various experiments have been made in dressing and blending of coals, sintering of iron ores, and reduction of the coke consumption ratio. The present consumption ratio of high-coking

Dockyard operations at Tsurimi, Nippon Steel & Tube Co. Ltd.



Unloading dock at Hirohata works, Fugi Iron & Steel Co. Ltd.

coal, imported for producing blast furnace coke, is 45 to 50 pct. Details of coal consumption in the iron and steel industry are shown in Table III.

As future coal demand increases, the ratio of imported coal is expected to increase because of insufficient Japanese coal reserves, even in comparatively abundant low-coking coal. Government scientists have expressed the opinion that Japanese coking coal supplies could be increased only from 3.8 million tons in 1956 to 5.8 million tons in 1962, while coal imports probably would rise from 3.2 million tons to 8.5 million tons during the same period. In anticipation of this coal shortage, Australia has been proposed as a possible source for imports of low-coking coal. Future coal imports from mainland China may be expected, but, despite transportation advantages, Chinese coal has a high ash content. American coal, on the other hand, has a lower ash content and is a stable supply source, but the advantages are offset by the cost of freight and distance.

Scrap: About 30 pct of Japan's scrap iron needs are supplied by imports (see Table IV). Scrap iron is the most unstable item in the cost picture, and, to reduce dependence on scrap iron, the LD converter process and other new techniques have been widely introduced.

Since Japan finds it increasingly difficult to obtain high-quality scrap iron on the world market, efforts have been made to restrict the use of scrap iron to superior grades, while a coordinating committee, composed of Japanese steel makers and dealers, helps stabilize the supply.

Iron and steel market

The years from 1950 to 1956 reflect a steady growth of steel demand in Japan. In that period, steel industry production rose 9.4 pct annually, while the gross national product increased by 6.5 pct annually. From 1953 to 1957, the shipment of ordinary steel products increased from 1,520,000 metric tons in 1953 and 5,620,000 metric tons in 1954 to 9,180,000 metric tons in 1957.

In Japan, steel demand is based mainly on capital goods industries. Consumer goods industries are less important because of the comparatively low level of national income, although the rising living standard has given increased importance to durable consumer goods, like automobiles, washing machines, and refrigerators. Table V shows the differences in the steel demand picture by comparing actual shipment by various fields of consumption in Japan and the US.

In the United States, steel demand centers around automobiles, machinery, and construction, and demand is supported by capital and consumer goods. In the future, the Japanese iron and steel industry will develop and expand particularly in capital goods and machine-producing industries, as well as in durable consumer goods industries.

The Japanese iron and steel industry has developed as an export industry in order to pay for its own imported raw materials. The ratio of steel export to steel production was 14.1 pct in 1956 and 9.7 pct in 1957. A marked trend in Japan toward the exporting of chemicals and heavy industrial products, in contrast to a previous emphasis on the exporting of lighter goods, such as textiles, has been noted during the past few years. The steel industry accounts for a large share of the heavy industry exports.

Most steel exports are sent to Southeast Asia, North America, and South America, but, when conditions require, Japanese steel products are exported to Western Europe. Among the major steel products destined for markets abroad are galvanized sheets, plates, heavy rails, bars, ferroalloys, and secondary steel products. Steel bars and wire rods are being exported to the US.

Since Japan lacks the stabilized steel markets of countries like the UK, Germany, and Belgium, the iron and steel industry of Japan is seeking to cultivate less-developed areas, Southeast Asia in particular, in efforts to secure the necessary stable markets. These latter countries, in turn, are placing greater emphasis on industrial expansion, and Japan hopes, therefore, to continue supplying them with finished goods in return for raw materials. Japan's present steel exports are mostly direct, in the form of rails, sheets, etc., but the future will see increasing exports of ships, machinery and other *indirect* steel products.

Production technique

Through new techniques and continuous research, Japan has done much recently to exploit domestic mineral resources. Attention has been focused on

Table III. Details of Siderurgical Coal Consumption
(Unit: 1000 metric tons)

	Imported Coal			Japanese Coal			Total		
Year	High-Coking	Low-Coking	Total	High-Coking	Low-Coking	Total	High-Coking	Low-Coking	Total
1953	2,374.3	394.4	2,768.7	269.7	2,403.6	2,673.3	2,744.0	2,798.0	5,542.0
1954	2,229.3	143.4	2,372.7	264.6	2,478.3	2,742.9	2,493.9	2,621.7	5,115.6
1955	2,167.4	28.1	2,195.5	321.7	3,023.3	3,345.0	2,489.1	3,051.4	5,540.5
1956	2,688.7	16.7	2,705.4	294.6	3,421.7	3,716.3	2,983.3	4,438.4	7,421.7
1957	2,949.6	285.6	3,235.2	311.6	3,521.4	3,833.0	3,261.0	3,807.3	7,068.3

Table IV. Trends of Srap Iron Demand and Supply
(Unit: 1000 metric tons)

	Domestic Supply				Import				Total, Domestic and Imported
Year	Consumption	Purchased	Returned Scrap	Total	India	US	Others	Total	
1953	5,126	1,857	1,927	3,784	346	78	717	1,141	4,925
1954	5,056	2,009	2,362	4,371	153	336	489	978	5,349
1955	6,063	2,610	2,707	5,317	129	657	501	1,287	6,604
1956	7,186	2,585	3,024	5,609	165	1,783	567	2,515	8,124
1957	7,846	2,420	3,364	5,784	95	2,371	862	3,328	9,112

iron sand, pyrite cinder, open-hearth slag, and blast furnace flue dust, as well as on the special technical problems of the Japanese iron and steel producers. In blending the various imported ores, for example, producers must overcome complications in pig-iron making operations resulting from different compositions in the imported and domestic ores. Techniques for solving this problem have reached a high level of efficiency, especially in regard to sieving, self-fluxed sinter manufacture, and ore bedding.

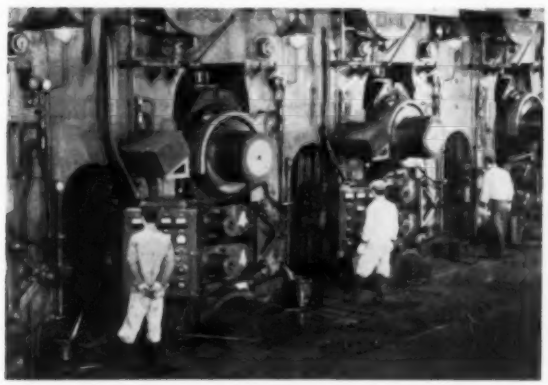
Since the necessary high-coking coal must be imported at considerable cost, scientists have made much progress in adapting Japan's abundant low-coking coal for the manufacture of coke. The technique of coal blending and dressing has reached an advanced stage by these means.

Blast furnace operations have been improved in numerous ways by increasing furnace volume, use of carbon blocks, improved quality of refractories, automatic control and by other means. The results of these advances are reflected in a more favorable coke ratio and in greater furnace capacity. Coke ratio per ton of pig iron reached a level of 700 kilograms in 1957 and 650 kilograms in 1958, and a coke ratio of 600 kilograms was obtained recently by the efficient use of self-fluxing sintered ore.

As previously mentioned, about 30 pct of Japan's total scrap iron consumption is supplied by imports, especially from the US and India. A stable supply of scrap iron is not possible, however, because of a recent decline in the quality of scrap available on the international market. Therefore, to lessen Japan's dependence on imported scrap, there is a tendency throughout the iron and steel industry to adopt the LD process (top-blown oxygen converters). At present there are two 50-ton LD converters, in operation since 1957, at Yawata Steel Works, and two 42-ton converters were installed in 1958 by Nippon Steel & Tube Co. Many other companies are planning to make similar installations, and it is expected that by 1962 a total of 22 LD converters will be in operation, having a total production capacity of 4,770,000 metric tons.

In open-hearth operations, oxygen steelmaking has progressed toward a higher quality product at a reduced cost. The amelioration of refractory bricks and exhaust disposal problems are now being studied by the steel industry.

The iron and steel industry, in conjunction with the First Rationalization Program of 1951, has promoted modernization of equipment and the cutting



Cold strip mill at Yawata works, Yawata Iron & Steel Co. Ltd.

Table V. Actual Steel Shipment by Different Consumption Fields in Japan and US (Unit: 1000 metric tons)

Fields	Japan Contracts in 1958 (April to June) Quantity	Japan Pct	US Shipment in 1957 Quantity	US Pct
Rerolling	281	17	5,603	6
Construction	252	15	12,523	16
Automobiles	63	4	14,227	18
Rails, rolling stock	126	8	4,149	5
Shipbuilding	170	10	1,278	2
Machinery	90	5	4,512	5
Electric machinery	57	3	2,086	3
Containers	57	3	6,238	8
Other fields	16	1	10,203	13
Warehouse merchants	298	18	14,507	18
Total domestic use	1,410	84	75,326	94
Export	274	16	4,569	6
Grand total	1,684	100	79,895	100

of production cost by means of increasing capacity and steel-tapping quantity, improvement of yield, and decrease of heat consumption per unit. At present the Second Rationalization Program for expansion and modernization is being carried out. Heavy plate mills in the 160-in. wide class, ranking in the world's highest level, are already in operation, and strip mills, continuous tinning and galvanizing lines, large and medium tube mills, and wire rod mills are now under construction. The capacity of blooming and slabbing mills has been increased to accommodate larger ingots. Of particular interest is a proposed fully integrated steelmaking plant which will be built in connection with the expansion of strip mills.

As one example of the present expansion plan, the Yawata Iron & Steel Co. is engaged in the construction of the Tobata steel works on 9.6 million sq yd of reclaimed land. This new works will comprise initially two 1500-ton blast furnace units, two 60-ton top-blown converters, two lines of hot-strip mills, and two lines of cold-strip mills (which already have been installed) and a third line of cold-strip mill now under construction. A 30,000-ton ore carrier can dock at the works, and each of two unloading units can remove 1000 tons per hr. New harbor facilities will accommodate ore carriers of between 40,000 tons and 60,000 tons. The Tobata steel works' No. 1 blast furnace will begin operation in September 1959.

Japan is second to the US in the number of strip mills. These strip mills, which produce a maximum sheet width of 6 ft, enable Japan to produce large quantities of high-quality steel sheets and plates for the manufacture of machinery, automobiles, and other rolling stock.

Eight new lines of hot-strip mill with a total capacity of 5,140,000 tons will be installed, it is expected, by 1962, while cold-strip mills will have the total annual capacity of 3,020,000 tons by 1962. Investment in such equipment amounts to 0.9 pct of the total national annual income, which is an equal percentage to that of West Germany.

Exacting quality control is practiced in the iron and steel industry, contributing thereby to the development and standardization of high-grade steel. As a result, high-quality products, such as deep-drawing sheets of high-tensile welding steel, ship plates, and electrical steel sheets, are manufactured. Intensive studies and experiments are also being carried out on the important problems of direct reduction of ore, continuous casting, hot extrusion, and vacuum casting.

METALLURGICAL RESEARCH IN JAPAN

Due to the difficulties of translation, much of Japan's research has little effect in other parts of the world. This is a summary of past and current work in research and development, written exclusively for JOURNAL OF METALS *by one of that country's most distinguished metallurgists.*

by Tokushichi Mishima

METALLURGICAL research of a fundamental nature can be said to date from 1922 in Japan, when the late Dr. Kotaro Honda founded the Research Institute of Iron and Steel in Sendai, which was later attached to the Tohoku Imperial University. Since that time, the amount of research has grown steadily, not only on iron and steel, but also on copper, aluminum, magnesium, other nonferrous metals, and various alloy steels. Outstanding in this regard was improvement of the duraluminum alloys, that gave rise to the present alloy 75 S and work on the problem of white spots in nickel-chromium steel.

For about ten years during and after World War II, Japan fell far behind in research and its applications to practice, but through the cooperation of the US and European countries, the metals industries, and their allied research efforts, have been restored and in many cases now exceed pre-war levels.

Professional societies

There are seven leading societies in the metallurgical field in Japan: Foundryman's Society, Iron & Steel Institute, Institute of Metals, Welding Society, Light Metals Society, Metal Finishing Society, and the Mining & Metallurgical Institute. Papers presented before these societies have increased from year to year; more than 500 were presented before the Iron & Steel Institute and the Institute of Metals in 1958. Unfortunately, these are largely written in Japanese, which drastically limits their effectivenesss to foreign workers. However, since 1957, the *Japan Science Review* has undertaken to publish a semi-annual report in English, containing abstracts of all papers published in the journals of these societies.

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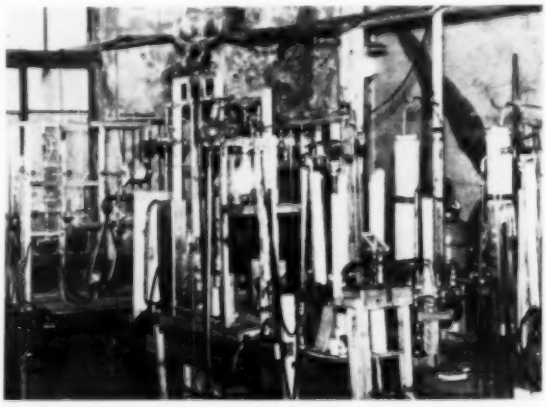
Research expenditures

According to an investigation carried out by the Science and Technology Agency of the Japanese government, nearly $10 million was expended by the 46 leading research organizations during 1958, corresponding to 0.5 pct of the gross sales of iron and steel. Only two Government research institutes are entirely devoted to metallurgical work, but there are many national and private organizations, as well as industry-sponsored groups, which perform a large amount of work. Following is a brief description of research work in various fields of interest.

Iron and steel

Blast furnace: Operations using 100 pct self-fluxing sintered ore have been successfully carried out by Yawata Iron & Steel Works and Sumitomo-Kokura Steel Works; over a period of one month, a coke



Apparatus used for the study on the activity of carbon and oxygen in liquid iron (by Matoba and Ban-ya).

rate of 550 kg per ton of pig iron was obtained. The ore was sintered with 10 to 15 pct limestone and was found extremely easy to reduce. (*An article on this development will appear in the April issue of* JOURNAL OF METALS—*Ed.*) Utilization of radio-isotopes to study gas distribution and the lowering rate of charged materials in the blast furnace has also been carried out.

Open hearth: Use of oxygen in open hearth shops has spread rapidly; enrichment of combustion air to 25 pct O_2 during meltdown was found to speed the melting of cold scrap without damage to refractories. Oxygen lancing during refining accelerates carbon drop, increases bath temperature, and reduces the amount of limestone and ore additions necessary. Several shops have reported outputs increased from 25 to 40 tons per hr, while fuel consumption has been reduced.

Electric furnaces: Most large electric furnace plants now have their own oxygen plants, and practically all stainless steel heats are treated this way in order to reduce carbon down to the low levels now required. Oxygen lancing also has made possible the recovery of thousands of tons of stainless steel scrap.

High-temperature metals

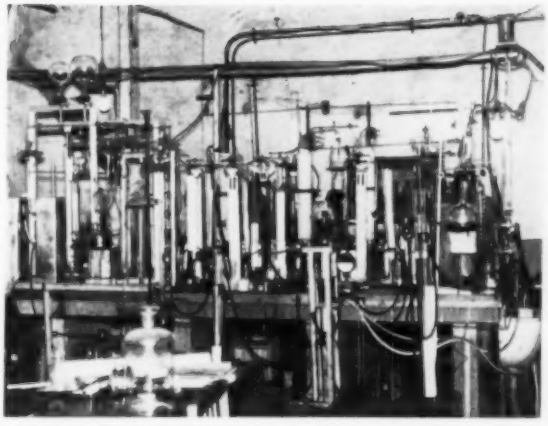
Japan ranks among the leading producers of reactor-grade titanium and zirconium sponge. The Kroll process is generally used, and purities obtained are very high. Vacuum melting has also been introduced since the war; consumable electrode arc melting will soon be used on titanium, zirconium, and their alloys, and several vacuum units are already in operation in the steel industry. Kobe Steel Works has reported much-improved properties through vacuum melting of bearing steel, chrome-vanadium spring steel, and many tool steels. Vacuum degasing units capable of larger ingots and complete vacuum melting of special duty steels are in the offing.

Fabrication

Shell-molding for castings, continuous casting, extrusion with glass lubricants, Sendzimir-type rolling mills, and investment casting are all fabrication techniques recently added to production facilities. Investment casting was originated in Asia more than a thousand years ago as a method of producing artistic articles such as statues. Many *Buddhas* cast in this manner over 1200 years ago may still be seen in the old temples in the Kansai district. Currently, however, the process is being used to produce jet engine parts. Shell molding is being done on a moderate scale, producing iron as well as nonferrous castings.

Magnetic materials

Japanese research in the field of magnetic materials is world renowned. This includes the 1916 discovery of the K. S. magnet by Dr. Honda, the original ferrite magnet by Drs. Kato and Takei in 1930, and the M. K. magnet in 1932. (*Dr. Mishima himself is responsible for the most important of these, the M.K. magnet, now well known as the Alnico alloy. It was discovered in the course of an investigation of the effect of addition elements on the Curie Temperature of certain iron-nickel alloys. Ed.*) Work on these materials has continued, but only one new alloy has been put into production since the War, this containing iron, aluminum, and carbon. Sintered magnets of the manganese-bismuth system and barium oxide-ferrite system are also under study. In electronic materials, development of vacuum-melted iron-aluminum and iron-aluminum-silicon alloys by a special arc melting device for magnetic applications is outstanding.



Parts of the apparatus for the study on the solubility of nitrogen in liquid iron alloys (by Matoba and Kasamatsu).

Nuclear metallurgy

Research in this field began only a few years ago, and Japan's first reactor, of the boiling water variety, went critical in 1957; a second is scheduled for operation last fall. Production of uranium metal began in January of this year, with production of about one ton per month. The Japanese Atomic Energy Research Institute, along with many other laboratories, is carrying out work in such fields as corrosion of aluminum in high-purity water, zirconium and magnesium alloys for cladding purposes, and corrosion of stainless steel. Production of thorium and production and fabrication of beryllium are also being studied. A completely Japanese-made research reactor with natural uranium fuel and graphite moderator will go into operation in July 1960.

Metal physics

Japanese work in this field is well known to the world's physical metallurgists. The late Dr. Keiji Yamaguchi was a pioneer; his theory on the mechanism of reversion phenomena is well known, as is Dr. Matano's equation on the diffusion of metals. The theory of age-hardening received impetus from the work of Drs. Sugiura and Goto who, between 1925 and 1928, used the expression "one step before the beginning of actual precipitation" to describe what is now the Guinier-Preston zone. Reaction kinetics of recrystallization, lattice imperfections, radiation damage, quenched-in vacancies, and ordering are among the subjects currently being studied. A Japanese electron microscope, believed to have the highest power in the world, has aided these studies considerably.

Conclusions

Though this is not a complete summary of Japanese work in metallurgical research, it is hoped that a general picture of what is being done will serve to increase the exchange of information with workers in the US.

Japanese Research on

PHYSICAL CHEMISTRY OF STEELMAKING

. . . Briefly summarizing the work of Japanese investigators on this important aspect of metallurgical technology.

by Tasuku Fuwa

BECAUSE of the handicap caused by language difficulties, less than 10 pct of the papers published in Japan on physical chemistry of steelmaking have been translated into English. Also, Japanese journals which are regularly translated, have a small circulation, due to lack of knowledge of their existence. This report, therefore, summarizes laboratory work being done by Japanese investigators on iron and steel in the liquid state. Pilot plant work and research on ingot-making have not been included.

The most active centers of physical-chemical research in steelmaking are the ferrous metallurgy laboratories of the seven former Imperial Universities, Hokkaido, Tohoku, Tokyo, Nagoya, Kyoto, Osaka, and Kyushu. Long range aims of this research are utilization of low-grade iron ore, domestic sandy magnetite, and high-sulfur iron ore. Because of Japan's poor supply of natural resources, this problem is of pressing importance. However, Government grants for research are only one-third of prewar levels, which limit all activities.

Both industry and the universities cooperatively support two influential committees of the Japanese Society for Promotion of Science (Nihon Gakujutsu Shinko Kai). These committees, the 19th Committee and the 54th Committee, play a large role in the planning of laboratory work and all kinds of research in manufacturing of iron and steel. The 19th Committee, for steelmaking and steel products, was organized by the late Dr. Kuniichi Tawara in 1934, who led this group as president for fifteen years. Now his position is filled by Dr. Hiroshi Sawamura. Ten years after the founding of the 19th Committee, Dr. Tawara also organized the 54th Committee for pig iron manufacturing. Dr. Sachio Matoba succeeded him as president in 1949.

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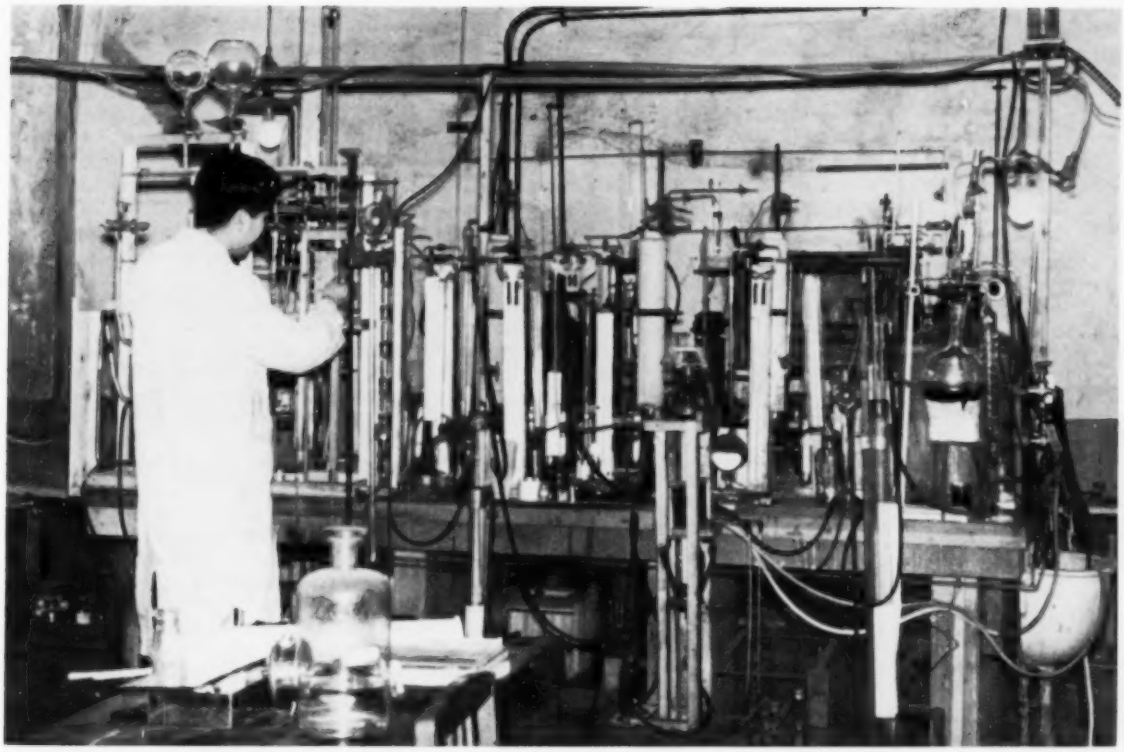
Both committees consist of professors of ferrous metallurgy or chemistry and leading staff members of research divisions in each iron and steel company. More than 6000 technical papers have been issued from the 19th Committee, covering rapid chemical analysis, including instrumental analysis, pyrometry, sources and elimination of flakes, controlling austenite grain size, and other cooperative studies on current topics. Also contributing to the work of this combined effort is a subcommittee of the 19th Committee specializing in physical chemistry of steelmaking, headed by Dr. Matoba.

Scope of research

The first physical-chemical research on steelmaking was begun by Genji Oishi in 1928 on the equilibrium distribution of manganese between molten iron and FeO-MnO-SiO_2 slag. The first successful experimental study on the equilibrium of carbon and oxygen in molten iron with the CO-CO_2 mixture was performed in 1936 by Matoba. In the forties, study on gas-metal equilibrium was carried on by Z. Shibata and Tajiri, but recently it has been undertaken by many people.

Fe-C-O system: The equilibrium between carbon and oxygen in molten iron and the CO-CO_2 mixture was repeatedly studied by Ban-ya and Matoba, covering wider carbon concentrations in molten iron than was undertaken in the previous work mentioned above. Their work was extended to measure the effect of alloying elements on the activity of carbon. Research on the effect of nickel was completed.

Fe-O-H system: The equilibrium of oxygen in liquid iron with H_2-H_2O mixtures has been studied by three separate groups: Gunji and Matoba, Sakao and Sano, and Watanabe and Sanbongi. They were concerned with the effect of alloying elements on the activity of oxygen in molten iron; the effect of aluminum and boron, measured previously by Yagihashi; that of vanadium, already measured by



Apparatus for the study on the activity of carbon and oxygen in liquid iron, set up by Drs. Matoba and Ban-ya, with Dr. Ban-ya in the foreground.

Shimose; that of silicon, which had been measured by Kuwana and Matoba, who purposely disregarded the formation of silicon monoxide; and the effect of copper and manganese, presently under study by Gunji and Matoba.

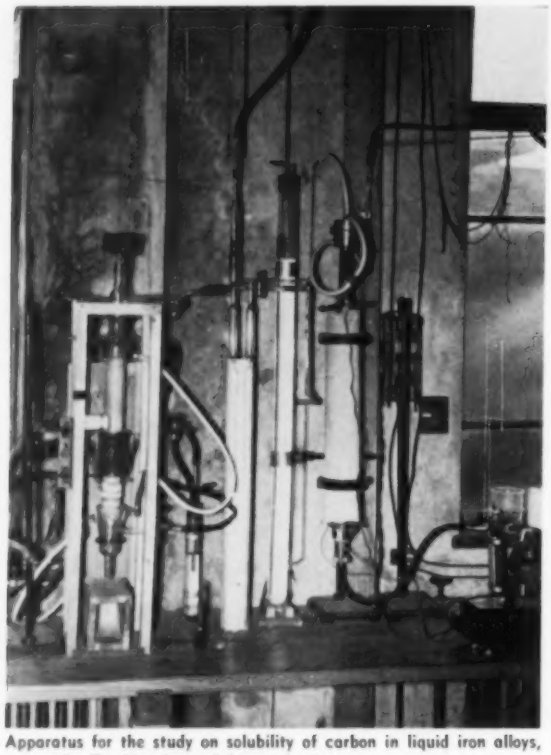
Fe-S-H system: The equilibrium of sulfur in molten iron with H_2-H_2S mixtures was determined by Matoba and Uno, including the effect of manganese on the activity of sulfur in iron. Recently, the effect of tungsten on the activity of sulfur in iron was measured by Morita and Adachi.

Solubility of gaseous elements: On the solubility of hydrogen in iron, there is a classical work by Iwase and his co-workers. Solubility of nitrogen in molten iron and alloys was measured and discussed by Tsunezo Saito (referred to as just Saito) from the viewpoint of statistical thermodynamics. Narita and Shimose studied the equilibrium of nitrogen with zirconium, titanium, vanadium, and aluminum, respectively, in molten iron. Solubility of nitrogen in molten iron, showing the effects of vanadium, silicon, copper, nickel and chromium, was studied by Sano and Minowa. According to the recent work by Kasamatsu and Matoba, it was disclosed that Sievert's law was not valid for the solubility of nitrogen in molten iron under less than one atmosphere pressure. Effect of alloying elements on the solubility of nitrogen has been under study by Matoba and one of his students, and also by Maekawa and his coworker.

Solubility of carbon: Solubility of carbon in molten iron has been measured by Sanbongi and Ohtani, Ban-ya and Matoba, and Sano and Inoue. The work of the first two groups was connected with the effect of chromium, manganese, and silicon on the solubility of carbon. The equilibrium between manganese and sulfur in molten iron saturated with carbon was studied by Sano and Inoue, and the effect of silicon or phosphorus on this equilibrium was also disclosed. Moreover, their work has been extended to the study of the equilibrium between chromium and sulfur. The effect of arsenic and tin on the solubility of carbon was studied by Toshisada Mori, and the effects of tin, tungsten, molybdenum, cobalt, nickel, copper, and titanium on the solubility of carbon has been measured by Matoba and a student.

Slag-metal distribution: A lot of work has been done by Matoba and his students on the equilibrium distribution of various elements between carbon-saturated iron and blast-furnace-type synthetic slags, measured under an atmospheric pressure of carbon monoxide. Recently, Sawamura and his son remeasured the distribution of silicon. Niinomi, Matsushita and Kanamori also remeasured the distribution of chromium in a similar condition. The equilibrium of chromium distributed between basic slag and molten steel was studied by Taiichi Saito. In addition, the equilibrium study of silicon between silica-saturated slag and molten iron was completed by Matoba, Sanbongi, and Nakamura under a controlled H_2-H_2O flow.

Hydrogen problem: It was disclosed by S. Kobayashi's classical work that residual hydrogen content in an ingot is correlative with mean humidity of the atmosphere on the heat. The problem dealing with flakes, caused by hydrogen, was one of the first projects to be studied by the members of the 19th Committee. Although the method of determination of hydrogen in steel was standardized in laboratories, most of the work on this project was carried out in practical furnaces. However, Sawa reduced the time necessary to determine hydrogen content in steel by



Apparatus for the study on solubility of carbon in liquid iron alloys, set up by Dr. Matoba and his students.

vacuum fusion, combined with the thermal conductivity method. He measured hydrogen content in slag equilibrated with H_2-N_2, and H_2-H_2O-N_2 mixtures, and equilibrium of hydrogen in slag and metal. Yoshii studied the effect of humidity of the atmosphere during pouring on the residual hydrogen in an ingot. This had been previously studied by Matoba and his students, who exposed molten metal in a controlled H_2O-N_2 flow.

E.M.F. method: Electrochemical study on steelmaking was pioneered by Onaka in 1940, using a silver-oxygen electrode to measure the oxidizing power of molten slag and the oxygen potential of molten steel. After World War II, Sanbongi and Ohtani built a carbon concentration cell with carbide slag to determine the activity of carbon by electromotive force measurement. They had difficulty determining true cell reaction, as Esin and Garrilo did in Russia, because no theory of ionic processes in slag, at least so far, gives the value for the number of electrons associated with the transfer of one atom of carbon. Despite this, they were the first to reveal the activity of carbon above 4 pct from dilute solution in molten iron. Furthermore, Ohtani continued his work to measure the activity of each solute in the molten ternary Fe-C-Si, Fe-C-Mn, and Fe-C-Cr systems. By using the electromotive force method, Sanbongi and Omori also measured the activity of silica and alumina, measured by Matsushita and Sakagami, in the iron-blast-furnace-type slag of CaO-SiO_2, CaO-SiO_2-Al_2O_3, and CaO-MgO-SiO_2-Al_2O_3.

Electrical conductivity measurement: Systematic work on the electrochemical properties of molten slag, including measurement of decomposition voltage, density, and electric conductivity of synthetic slags, was performed by Matsushita and Kazumi Mori, who were later joined by Sakagami. When K. Mori measured the electric conductivity of various type of slags containing TiO_2, he disclosed the characteristic behavior of TiO_2. This system was also measured by R. Sato and Sakagami. A study on oxidizing slag was made by Adachi and Ogino, using the electric conductivity measurement.

Viscosity: Saito and Y. Kawai measured the viscosity of molten slag in the CaO-SiO_2-Al_2O_3 system plus the effect of MgO on the viscosity. The interface tension between molten slag and metal was measured by K. Mori.

Kinetic studies: Carbon elimination in molten iron by oxidizing gas was studied by Niwa and Katsufuji, and by Matoba and his students. This aspect of the mechanism of decarburizaion in steel has also been presented by Niwa and Shimoji. Fujii studied the rate of the reaction of carbon in molten iron with oxide crucible materials.

Desulfurization in molten iron by gas was studied by Niwa and Katsufuji, using hydrogen or oxygen. Desulfurization by molten slag was studied by Fujii, and the study of desulfurization by calcium carbide or CaO was done by Sawamura and by Yoshii. Using isotope S^{35}, Saito and Kawai studied the rate of sulfur elimination from carbon-saturated iron by molten slag and the effect of silicon and manganese on the rate of desulfurization. Since the advent of the oxygen top-blowing converter method for steelmaking, phosphorus has become one of the targets of interest from the viewpoint of not only thermodynamics but kinetics. Many groups have started study on this topic.

By means of a tracer method, diffusion of sulfur in molten CaO-SiO_2-Al_2O_3 slag was measured by Saito and Kawai, and the diffusion of calcium in the same type of slag was studied by Saito and Maruya. Saito and Maruya also carried out the study of diffusion of silicon and manganese in molten iron saturated with carbon. Kawai also measured the diffusion of sulfur in molten steel.

Another tracer study was applied to the origin of non-metallic inclusions by Saito, Shimanuki and Sugiyama, using Ca^{45} and Zr^{95}. Concerning non-metallic inclusions, the mechanism of its formation has been under study by many people.

Statistical-Thermodynamic studies: Based on the concept of the quasi-crystal, statistical thermodynamics was introduced to calculate some reactions of steelmaking by three separate parties: Takeuchi and his co-worker, Saito, and Horikawa. This type of calculation was applied to the study of equilibrium between molten iron and such gas phases as H_2-H_2O or CO-CO_2 mixtures, the gas-molten iron alloys reaction, and has been extended by Takeuchi and Furukawa and by Yoshida to the study of interaction between oxidizing atmospheres and molten slag.

Although ingot-making has been omitted in this paper, the classical and comprehensive research by Kohira should be mentioned. Recently, Satoi has performed similar work, and Fujii has done interesting work on formation of gas blow-holes in ingots.

Conclusions

Much of the information in this report is based on the *Journal of the Iron and Steel Institute of Japan* and the *Journal of the Japanese Institute of Metals.* It is hoped that in the future there will be an expanding exchange of information in this field between Japanese workers and their American and European colleagues.

FLUOSOLIDS ROASTING OF SULFIDES
Its Meaning to Japan's Economy

by Hidesaburo Kurushima and R. M. Foley

FluoSolids treatment of Yanahara pyrrhotite has given Japan's Dowa Mining Co. a profitable return on copper, sulfuric acid, and iron ore. This means a material increase in the country's natural resources.

ABOUT 25 pct of all Japanese pyrite comes from the Yanahara mine on Honchu Island. For the past 40 years, lack of an economical recovery process forced the operator, Dowa Mining Co., to sell the pyrite for its contained sulfur only, leaving 7 million tons of high-grade iron ore waste. Introduction of the Dorrco FluoSolids roasting system enable the company to make use of its iron sulfides and also to find a market for the mine's considerable pyrrhotite production.

The success of this project is of great importance to Japan's economy, since it points the way toward material increase in her natural resources. Prior to use of the present process, no practical method was available for commercial exploitation of known large tonnages of pyrrhotite, while the copper content of the even larger deposits of pyrite made the roasted residue unacceptable for the iron and steel industry. In Europe, large amounts of copper-bearing pyrite cinder are given a chloridizing roast for separation of the copper and iron, but this treatment is not economical in Japan where salt is imported from as far away as Egypt.

Yanahara ore

The pyrite deposits at Yanahara are generally enclosed in an irregular layer of pyrrhotite, and small veins of pyrrhotite occur in the pyrite. To be commercially attractive the pyrite has had to contain about 50 pct S. To maintain this grade, mining was selective, resulting in a considerable loss of pyrite in the mine because of the irregular boundary between the two minerals. Likewise, the pyrrhotite from the small veins had to be discarded by hand picking.

There was no market at all for the pyrrhotite because consumers objected to the higher freight per unit of sulfur. Additional drawbacks included the danger of spontaneous combustion in transit and storage, and the tendency of the pyrrhotite to fuse during calcination.

Dowa Mining had already successfully applied the Dorrco FluoSolid roasting system on sulfate roasting a complex sulfide concentrate containing copper, zinc and iron. This roast-leach-electrowinning process was described by the senior author in a previous paper.[1]

Test Program

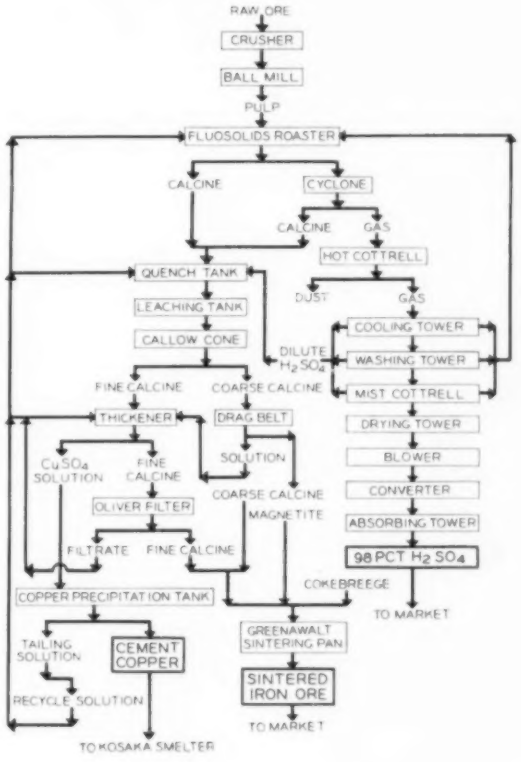
A test program was initiated, and Yanahara pyrrhotite was selected to be the test sulfide because utilization of this unmarketable material would be of greatest benefit to Dowa. Roasting tests were carried out in a 4-in. diam laboratory FluoSolids reactor.

Nine separate tests were carried out to determine the optimum range of temperature and SO_2 concentration required to obtain high copper solubility, low iron solubility, and high oxidation of sulfur. From these tests it was concluded that the system would satisfy requirements when operated at 625° to 650°C with 7 to 8 pct SO_2 in the exit gas. Therefore, it was decided to erect a commercial installation at Okayama, a city about 25 miles from the mine.

The first section of this plant went into operation in September 1953. Rated capacity of the roaster was 115 tpd and product targets were 3000 tons per month of 98 pct H_2SO_4 and 3000 tons per month of 60 pct Fe.

In July 1956 a second FluoSolids reactor of the same capacity was placed in operation. The SO_2 gas from this unit converter to acid in the original plant which had first been designed for capacity of 200 tpd of 998 pct acid. The leach plant and precipi-

OKAYAMA OPERATIONS



HIDESABURO KURUSHIMA is president, Dowa Mining Co. Ltd., Tokyo, and R. M. FOLEY is with Dorr-Oliver Inc., Stamford, Conn.

tation section were expanded to handle the increased tonnage. All decuperized residues are sent to Amagasaki Steel for treatment.

At present, approximate average copper analyses of the feed, calcine, and leach residue are 0.80 pct, 1.00 pct and 0.14 pct, respectively; copper solubility is 85 pct and recovery is 82 pct. Overall iron recovery is 99.0 pct.

Okayama roasting plant

Pyrrhotite feed analyzes about 50.4 pct Fe, 34.7 pct S, 1.1 pct Zn, 0.8 pct Cu, gangue minerals, and traces of other metallic elements. It is delivered to the plant by rail at −1 in. and stored in the open on a concrete pad where it is blended by the bedding system. The ore is crushed to −½ in. by a cone crusher and conveyed to the ball mill hopper by a skip hoist. The grinding circuit consists of a Marcy ball mill, sump tank, and a rubber-lined SRL pump to deliver the slurry to the storage agitator. The feed and water additions to the grinding circuit are controlled so that a 70 to 75 pct solids slurry is produced. A rubber-covered turbine agitator installed in a 8x8-ft wooden tank is used for surge storage and blending of the slurry. A typical size analysis of this feed is given in Table I.

Two air-operated ODS pumps in alternate cycles deliver the feed to the 20-ft ID FluoSolids reactor at a uniform rate. Roasting air is supplied to the windbox of the reactor by a 250-hp centrifugal blower capable of delivering 7400 cfm at 5 psi. The dust-laden gas leaving the reactor passes through two stages of cyclone collectors, a balloon flue, and a hot Cottrell for dust removal. Calcine distribution is as follows: overflow 48.5 pct, primary cyclone 40.3 pct, secondary cyclone 5.2 pct, and cottrell and flue 6.0 pct.

The reactions that occur during calcination are exothermic and much excess heat is generated in the reactor. To control temperature at the desired level, 85 lb of water per 100 lb of ore are used. Approximately 40 pct of this water is contained in the feed slurry, which is maintained at 70 to 75 pct solids. The balance of the water is added automatically to the feed guns by the temperature controller.

Overflow and cyclone products are collected in quench tanks. Quenching solution is made up of recycle from the copper precipitation tanks plus dilute acid from the gas washing tower.

Leaching operations

Copper values are concentrated in the coarse and fine fractions of the calcine, but leach efficiency shows a progressive increase with decreasing grain size. Individual size fraction copper assays and copper distribution of the final leached residue are given in Table II.

Most of the leaching takes place in the quench tanks, but 15 to 20 pct of the copper is leached out in agitators. The slurry from the agitators is classified in a Callow cone. The spigot product is given a two-stage wash in Esparanza-type classifiers while the cone overflow is washed in a two-stage CCD thickener system and dewatered on an Oliver filter. Washing efficiency is 95 pct for the classifier circuit and 95 pct for the thickener-filter circuit. The weight distribution is 30 pct spigot and 70 pct overflow, and moistures are 22 pct and 17 pct, respectively.

The pregnant copper solution contains 2.5 gpl Cu, 20 gpl Fe, and 5 gpl free H_2SO_4. It goes to cementation roughs where the copper is precipitated on scrap iron, aided by compressed-air agitation. The barren solution contains 0.3 gpl Cu, 23 gpl Fe and 4 gpl free H_2SO_4.

Table I. Size Analysis of Roaster Feed

Mesh	Ind. Weight, Pct
+32	3.9
+48	7.8
+60	4.2
+80	6.1
+100	11.3
+150	14.6
+200	3.3
−200	48.8

Table II. Screen Analysis of Copper Distribution in Leach Residue

Mesh	Weight, Pct	Decuprized Calcine, Cu, Pct	Copper Distribution, Pct
+32	1.2	0.19	1.6
+48	7.6	0.17	8.8
+60	4.3	0.13	3.8
+80	5.5	0.12	4.5
+100	9.2	0.12	7.6
+150	16.5	0.13	14.7
+200	7.3	0.11	5.5
+250	19.1	0.12	15.7
+325	1.8	0.17	2.1
−325	27.5	0.19	35.7
Average	100.0	0.146	100.0

Acid recovery

A Monsanto contact system is used to produce 98 pct acid. Exhaust gas from the roaster cyclones contains 7.5 to 8.0 pct SO_2, 0.5 to 0.8 pct SO_3, 7 pct O_2 and 11 to 13 grains per cu ft of dust. This gas is cooled to 500°C in the balloon flue before entering the hot Cottrell. From the hot Cottrell the gas passes through a conventional contact plant, which consists of gas washing and cooling towers, mist Cottrell, drying tower, blower, converters, and heat exchangers, and goes finally to the absorption tower.

Without recycle, the sulphur loss would amount to 22 pct of the total amount. Present sulfur loss of 12 pct is accomplished by recycling a portion of the excess barren solution from the cementation tanks to the FluoSolids reactor in place of water for temperature control (Japanese Patent 196,537). This solution, plus some of the solution from the gas-cleaning circuit, furnishes acid which improves the sulfating efficiency. Copper and iron are recovered from the barren solution, and the remaining excess solution is oxidized to precipitate the iron, then neutralized with lime and discarded.

Conclusions

The treatment of Yanahara pyrrhotite has been a profitable venture for Dowa Mining Co. In addition to the monetary return obtained from the sale of the copper, sulfuric acid, and iron ore, mining costs on the pyrite have been reduced. By mining both pyrite and pyrrhotite, the overall pyrite yield from the mine has increased and, now that pyrrhotite has been converted into ore, the mine reserves have been increased by more than 10 pct. Prospecting has also been simplified and has incidentally led to a new discovery which may total 20 million tons.

Reference

[1] H. Kurushima and S. Tsunoda: Hydrometallurgy of Copper-Zinc Concentrates at the Kosaka Smelter. The Dowa Mining Co., Japan. JOURNAL OF METALS, May 1955.

NONFERROUS EXTRACTIVE METALLURGY IN JAPAN

In a sense the saying "Japan is a museum of minerals" may be transformed to "Japan is a museum of extractive metallurgy". This review of some of the exhibits on display has been written especially for JOURNAL OF METALS *by one of Japan's leading authorities in this field.*

by Yoshiki Ogawa

JAPAN's development in the field of extractive metallurgy since the restoration of peace has been striking, the metals produced contributing very much toward the rehabilitation of the Nation. *Have-Not Nation* as we are, we are not so short of sulfide mineral resources; among others we abound in zinc and iron sulfides. As to the copper, we have for many centuries been self-supporting, even doing some exporting.

It should be noted here that Japan has often been nicknamed *A Museum of Mineralogy*, which implies that we are by no means lacking in variety of minerals. When, however, the quantity as well as the quality becomes the question, mineral deposits are mostly poor or complex in constitution. For instance there is the so-called *black ore*, which is a complex sulfide ore consisting of an intimate mixture of sphalerite, galena, and copper and iron pyrites associated with some barite. Perfect utilization of such ores has long been the problem of Japanese mineral engineering.

Such a handicap acted as an impetus for promoting research, some of which started in the first quarter of this century, building up certain fundamentals of nonferrous extractive metallurgy. During wartime, however, the nonferrous metals, except the light metals, were given rather secondary importance, and researchers in this field were in unfavorable conditions, not to speak of the disadvantage of exclusion from the technological progress of Europe and America.

Postwar developments

For a few years after the end of World War II, a miserable state prevailed until the activities of engineers and researchers were revived, taking advantage of newly introduced apparatus and methods.

The main viewpoints which acted as the impetus to the advancement of mineral engineering may be summarized as follows:

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1) Necessity of thoroughgoing utilization of domestic mineral resources, in particular the sulfide ores;

2) Rationalization of the process and apparatus of smelting;

3) Complete recovery of byproducts from the complex sulfide ores, including sulfuric acid recovery from smelter smoke;

4) Development of the utilization of smelter products (increasing the purity of metals to the highest level of international standards stimulated the demand, for example, of zinc and nickel);

5) Promotion of research activities.

At present about 60 smelters and refineries of nonferrous metals are operated by about 35 companies distributed widely over Japan (locations illustrated in Fig. 1). Among the companies, Dowa, Furukawa, Mitsubishi, Mitsui, Nippon Kogyo, and Sumitomo are especially prominent. The amount of annual production of principal nonferrous metals is given in Table I.

Copper

The conventional blast-furnace system of copper smelting has long been established in Japan with necessary modifications to meet local conditions. Naoshima plant of Mitsubishi Metal Mining Co. is the only example of reverberatory furnace smelting.

Postwar advancements have been remarkable, with copper production surpassing 111,000 metric tons, which was the wartime high. Major developments were:

1) Adaptation of sulfuric acid recovery to most copper smelters with consequent elimination of smoke pollution. Particularly noteworthy was acid recovery from waste blast-furnace gas; this was worked out at Shisakajima by Sumitomo Mining Co., by altering the furnace top and direct charging copper concentrates;

2) Autogenous or flash smelting following the Finnish model introduced in the Ashio mine of Furukawa Mining Co., producing daily 50 metric tons of copper and 150 tons of sulfuric acid (JOURNAL OF METALS, June 1958, p. 395);

Location of Japan's principle nonferrous ore deposits.

3) Slag-fuming process applied to zinciferous slag from the Mitsubishi reverberatory furnace at Naoshima, the first project of this type used in connection with copper smelting;

4) Hydrometallurgical process of recovering zinc and copper from the black ore developed at the Kosaka mine of Dowa Mining Co. by combining FluoSolid roasting with electrowinning (see p. 173);

5) Refined anode process adopted by Mitsubishi in place of the direct-cast anode from the converter (increased tank capacity and improved the purity of the cathodic deposit);

6) Progress in the recovery of selenium in the anode-slime treatment, especially by the pressure-leaching process, developed at the Nikko copper refinery of Furukawa Electric Co; this has supplanted the conventional dry method and results in more effective dissolution and higher recovery of copper, nickel, and selenium;

7) New direct-smelting process in converters operated at Hitachi smelter of Nippon Mining Co. by the use of oxygen-enriched air followed by the flotation treatment of converter slag. Points in favor of the process are the elimination of a roaster, a sintering machine, and a blast furnace, higher sulfuric acid recovery from sulfide sulfur, and profitable utilization of slag-flotation tailings as an iron ore;

8) Fundamental research involving a great deal of work on the study of the theory of copper smelting and electrolysis, for example, the sulfur-oxygen relations, the matte-slag relations, and the viscosity of slag.

Zinc

Having been recognized as the most promising metal of Japan, mining and metallurgical people concentrated their efforts on the utilization of domestic zinc resources by improving the methods of extraction, both dry and wet. Zinc production steadily increased to over 130,000 metric tons, the highest record in the history of Japan.

Fundamental studies of the general mechanism of roasting zinc ore have been underway for some time by university research workers. A number of reports along this line have been published.

Main objectives of our efforts were the following (and fortunately most of them have been fruitful):

1) Complete utilization of complex sulfide ores. The success of the Kosaka mine is remarkable, since a new system of hydrometallurgy based on Dorr's FluoSolid roaster enabled them to turn out electrolytic zinc side by side with the copper from the *black ore;* formerly the zinc went into the waste slag from the blast furnace;

2) Recovery of zinc oxide from various waste products of smelting by the Waelz kiln, the fuming furnace, and others;

3) A step forward to rationalization of Japanese zinc industry as exemplified by New Jersey Zinc Co.'s vertical retort process introduced at the Miike smelter, Mitsui Mining & Smelting Co. and St. Joseph's electrothermic process at the Mikkaichi smelter;

4) Improvement in the purity of zinc, in particu-

Table I. Production of Nonferrous Metals in Japan

Metal	Annual Production, Metric Tons 1957	Max. Prewar or Wartime	
Copper	142,223	111,360	(1943)
Lead	54,036	34,795	(1944)
Zinc	138,030	64,648	(1944)
Tin	1,280	5,663	(1942)
Nickel	7,252	1,823	(1941)
Antimony	1,469	10,804	(1916)
		2,480	(1941)
Aluminium	67,979	109,470	(1944)
Titanium	3,078	—	—
Gold	9.4	27.0	(1940)
Silver	263.8	357.9	(1939)
Mercury	409	239	(1944)

lar the four nines electrolytic zinc as the base of die casting alloys;

5) Development in the uses of zinc;

6) Fundamental studies both on pyro- and hydrometallurgy. Among those already carried out are the mechanism of roasting, the formation of zinc ferrite, chemistry of zinc-fuming process, and the behavior of impurities, particularly of lead and cobalt in the electrolyte.

Lead

The production of lead has increased steadily until the wartime high of 34,795 metric tons has been exceeded, mostly due to the activity in the zinc industry. As to the method of refining, Japan has long been accustomed to the Betts electrolytic process, although the sulfamate process has been tested, and its advantage in a smaller refinery has been confirmed.

As for research, emphasis has been placed on the following subjects: fundamental studies on the smelting reactions, physicochemical studies of the fire refining of crude lead, and the electrolytic process including fused salt electrolysis.

Gold and Silver

The gold industry of Japan has also been a puppet of fate through the last two decades. So, it is significant that the production of gold was restored to 9 metric tons and silver to 260 metric tons in 1957. Of the silver, 70 pct is used for photography, and the electrical uses come next in amount. The all-sliming process has been adopted by most of the gold mines with some modifications in the dressing technique. The use of domestic calcium cyanide as a cyanide reagent is commonly practiced at lower cost. An attempt has been made by some mines to test the regeneration of cyanide from foul solutions by the addition of zinc sulfate. The mechanism of cyaniding reactions has been studied extensively by Prof. M. Kameda.

Nickel

The vicissitudes of the nickel industry of Japan are also impressive. The metal was first produced in 1938 by the Sumitomo Mining Co., using imported New Caledonian ore, in order to comply with the defense program. Since the end of World War II, it was stopped until 1952, when the production was resumed. The peaceful demand for this metal has kept pace with the increasing output, while our production art has been making remarkable progress, resulting in a product of higher purity than foreign electrolytic nickel. The Shimura Kako Co. recently became the leading producer, turning out a greater amount of nickel than Sumitomo. Ferronickel production, including nickel output, exceeds 10,000 metric tons. Fundamental research has also been carried out on the smelting, electrolysis, and separation of nickel from cobalt, etc.

Titanium

Commercial production of ductile titanium in Japan dates back only to 1952. The technological development has been spectacular, turning out over 3000 metric tons of metal with the topmost purity after a few years. It is, however, regrettable that the domestic demand has not been duly developed. University people have also been immersed in fundamental studies.

Aluminum

Aluminum production steadily increased to 67,979 metric tons in 1957, a little over a half of the wartime level. As to the technology, improvement in power economy and the purity of primary aluminum is striking. It is also to be noted that aluminum refined as high as 99.998 pct pure is being produced in the Kikumoto plant of Sumitomo Chemical Co.

Other Metals

Tin, antimony, cadmium, bismuth, mercury, tungsten, and a small amount of molybdenum are produced in Japan. Somewhat small in scale as they are, most of these industries have undergone innovations in method and apparatus. In addition, magnesium recently came into production by the ferrosilicon reduction process in the Oyama plant of Furukawa Magnesium Co.

The metallurgy of minor metals, such as selenium, germanium, silicon, chromium, indium, tungsten, and molybdenum, has also been studied extensively at the universities, and many reports have been presented.

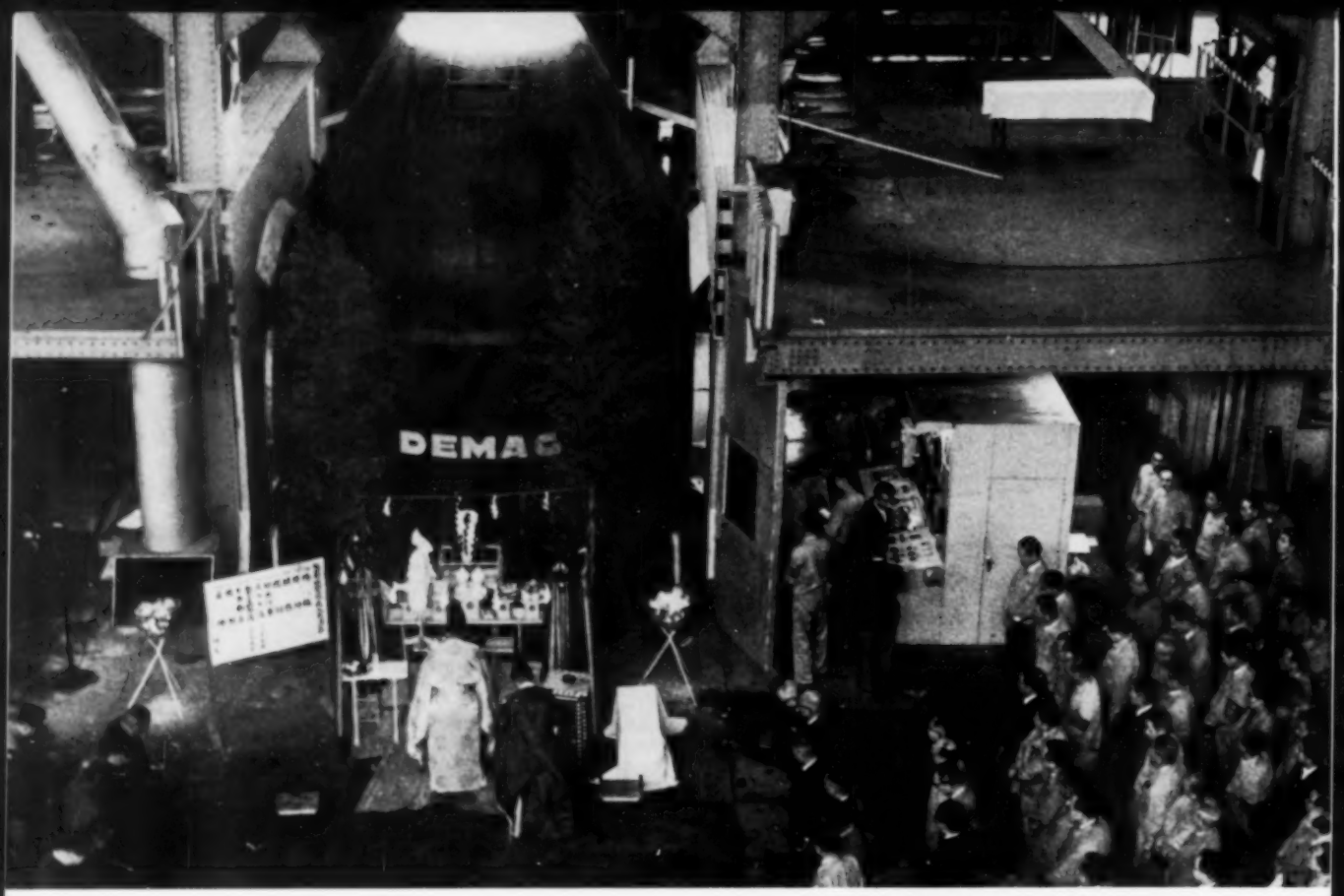
The Nuclear Fuel Corp. has recently been organized for the extraction of uranium from its ores. Fundamental research on the metallurgy of uranium and thorium was started in some universities.

Research activities

Research work in the nonferrous field is active in the departments of metallurgy and the research institutes of 19 universities and colleges as well as in the Government research facilities, such as the Resource Research Institute. Most of their results have been published in the *Journal of the Institute of Mining and Metallurgy of Japan*, and some in the *Journal of Electrochemical Society of Japan*, the *Journal of Japan Institute for Metals*, local mining journals, and university publications. The subjects of the papers in Japanese between 1945 and 1956 are listed in the *Journal of the Institute of Mining and Metallurgy of Japan*, vol. 72 (1956), No. 822.

Most of the large companies have their own laboratories to meet their unique demands; their results are, in general, seldom open to the public. Sometimes they appear mainly in the *Bulletin of Japan Mining Industry Association* along with other technical reports.

The affiliations among researchers and engineers are with the Japan Society for the Promotion of Science, the Metallurgy Div. of the Institute of Mining and Metallurgy of Japan, and the Electrochemical Society of Japan. On the other hand, factory engineers have organized the Japan Mining Industry Association for their meetings and discussions.



Dedication ceremonies of Japan's first LD converter.

LD STEELMAKING IN JAPAN

Although it is only one year since the LD process was first put into operation in Japan, four converters are already in operation, and by the end of 1962 the LD process will account for one quarter of Japan's total ingot capacity.

by Kaname Mochizuki

IN 1938, five 20-ton basic bessemer converters, the first in Japan, were put into operation at the Kawasaki works of Nippon Kokan K. K.

Japan has little high-phosphorous iron ore suitable for making basic bessemer iron; so to produce pig iron with 1.8 to 2.1 pct P, phosphorus rock from South Pacific islands was added to the blast furnace charge.

The basic bessemer converters were used mainly to produce mild steel for sheets, butt-welded pipe, round bars, and some free-cutting steel. Duplexing with a 20-ton electric furnace was practiced. But as demand for high-quality steel increased, the shortcomings of basic bessemer converter or thomas steel became more apparent, and improvement of its quality became one of the most important technical problems.

To make low-phosphorous, low-nitrogen thomas steel, the following methods were employed by Nippon Kokan:

1) A shallow bath was used; this entailed smaller charge, shorter blowing time, cooler refining by addition of iron ore and limestone, and lower blowing temperature. However, this had a certain restriction: tapping temperature of steel could not be lowered much due to the fact that it was to be bottom poured into small 1-ton ingots;

2) Oxygen-enriched air was used; an oxygen generator with 2000 normal cu m per hr capacity was installed in 1953, and the production efficiency was raised considerably by an enrichment of blowing air of 25 to 40 pct O_2. Nitrogen content of resulting steel was lowered to 0.005 to 0.012 pct;

3) Kawasaki works went into experimental blowing with open-hearth-grade pig iron in 1941, but ferro-silicon additions were often necessary, since blowing by plain air did not provide enough heat. With the adoption of oxygen-enriched air blowing, refining of this pig iron in a converter

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became practically possible. Thus, the use of both thomas pig iron and open-hearth pig iron, kept in separate mixers, came to be a normal shop operation, and by 1958, 1 million tons of steel was produced from open-hearth pig and 3½ million tons from thomas pig. Steel from open-hearth pig contains only 0.014 to 0.040 pct P. This is less than steel produced from thomas grades of pig iron and permits industrial production of seamless tubes from the converter process.

While studies for further improvement of thomas steel continued, experiments with a 5-ton LD converter were begun in 1952. In 1956, Nippon Kokan K. K. became the general licensee in Japan of this process by concluding an agreement with Oesterreichisch-Alpine Montangesellschaft. Operation of the first 43-ton LD converter was started in January 1958.

Layout of LD plant

Of the five 20-ton converters originally installed, two have been replaced by 43-ton LD crucible converters. The converter bodies are all-welded concentric types with detachable bottoms, made by Demag AG in Germany. For tilting, a hydraulic pump designed for the thomas converter is utilized. The oxygen plant is of Linde Frenkel design and can produce 4250 normal cu m O_2 per hr, with purity over 99.5 pct. To arrest dust, Baum Co.'s venturi scrubber was adopted; the de-dusting ratio is 98 to 99 pct. There are three dead mixers, two 550-ton and one 600-ton, which supply hot metal to both LD converters and open-hearth furnaces. Ingots are cast in 6-ton and 1-ton sizes, both by bottom pouring. Teeming of steel is done with a 50-ton casting car and a 65-ton ladle crane. The shop has a monthly capacity of 40,000 tons.

Crucible linings

Linings are tar-dolomite, made from local materials. Total thickness of the working lining and safety lining at the middle is 830 mm. A thomas converter bottom is utilized, with satisfactory results. Consumption of dolomite is about 7 kg per ton of ingot, and crucible body life averages 300 to 360 heats. Composition of dolomite in pct is shown below:

MgO	29.93 to 32.02
SiO_2	1.16 to 1.88
Fe_2O_3	0.25
CaO	62.66 to 64.86
Al_2O_3	0.65
Ig. loss	1.22 to 2.40

Volume of a crucible body is 32 cu m when it is new; this amounts to 0.68 cu m per ton of charged metal, considerably smaller than other LD converters.

Charging and operation

Composition of hot metal in the mixer is 4.1 to 4.4 pct C, 0.6 to 0.9 pct Si, 0.9 to 1.2 pct Mn, 0.300 to 0.400 pct P, and 0.030 to 0.055 pct S.

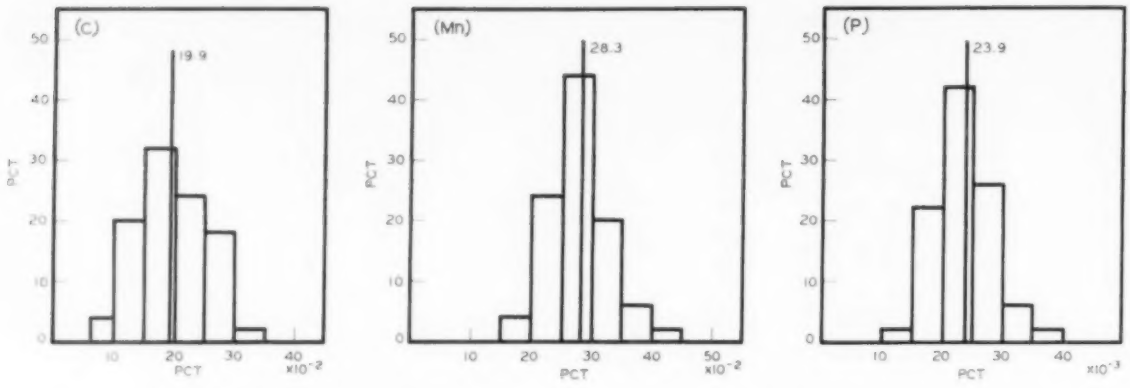
Since domestic iron ore of comparatively high phosphorous content is used, hot metal produced is higher in phosphorus than in other countries. Before the conclusion of the agreement with Alpine, a test on preparatory treatment of such hot metal was made. In this test, a blend of limestone and fluorspar powders was blown onto the surface of the hot metal bath by oxygen gas to form a low basicity slag. The experiment proved successful and low-phosphorous metal was obtained. However, such treatment is not considered necessary in the actual operation as performed today.

Up to 25 pct scrap may be used, according to the silicon content of the hot metal, but as there is a limitation on the available supply of scrap, and priority is given to open-hearth furnaces, scrap charged into the LD is restricted to less than 13 pct of the total charge.

Experiments are being made using only cold pig iron or iron ore, mill scale, and limestone as coolants, in place of scrap. These experiments should determine the practicability of 100 pct hot metal charge without risking any drop in the yield caused by metal being blown out during the process.

With a total charge of 47 to 52 tons and a blowing time of only 19 to 23 min, 35,000 to 39,000 metric tons of steel can be produced monthly by operation of one LD converter. Yield of sound ingots is 91 pct and can be said to be very good in view of the bottom pouring practiced.

LD converters in operation: left, blowing; right, tapping a heat.



Frequency charts of chemical composition of killed steel intended for structural use: analysis before Fe-Mn addition.

Range of products

Steels manufactured cover a wide range, from low-carbon steel such as skelps for butt-welded pipe hoops for cold forming, sheet bars, and materials for ferro-alloys, to high-carbon steels, up to 0.35 pct C, including seamless tube materials, steel bars for cold drawing, shapes, round bars, etc. Tests on boiler tubes and casings from LD steel to obtain approval of ship classification societies on shipbuilding steel materials, and it is expected that approval will be granted in the very near future.

The superiority of LD process in production of low-carbon steel is well recognized. A study is being made on a method to produce steel of medium and high-carbon contents without recarbonization by catching carbon in a soft blow. Although the maximum limit of phosphorus in pig iron will become a problem, the success of such a method will give an impetus to the development of the LD process in production of high-carbon steel and also low-alloy steels.

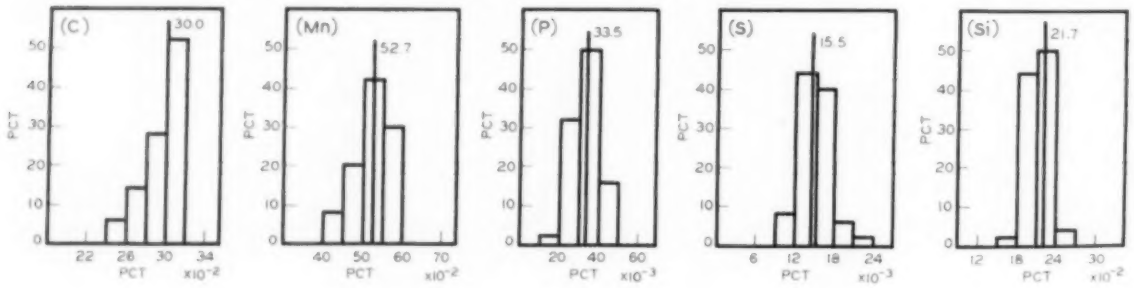
Future prospects

In addition to those at the Kawasaki works, there are two other 50-ton LD converters in Japan, which Yawata Iron & Steel Co. operates at its Kukioka works. By next year, two 60-ton LD converters at the Mizue plant of Nippon Kokan K. K., now under construction, and two 60-ton converters at Tobata works of Yawata will be completed. Both mills will go into the production of steel strip materials. Succeeding these, LD plants are also planned for Hirohata works of Fuji Iron & Steel Co., Kokura works of Sumitomo Metal Industries Co., Amagasaki Iron & Steel Co., and Nakayama Steel Co. By the end of 1962, the number of LD converters will total 18, with annual capacity of 4,720,000 metric tons, comprising about one quarter of total ingot capacity in Japan, and surpassing electric furnace capacity.

Summary

Although it is only one year since the LD process was first operated at Kawasaki works, the process has already proved itself to be very satisfactory in the operational phases as well as in the quality of steel produced. The conception of the converter process is being completely changed in Japan, as long strides are made towards production of kinds of steel formerly accepted as possible only by open-hearth furnaces. Success in the use of linings of domestic dolomite and in the use of hot metal with high phosphorous content without difficulty is of special significance to Japanese steelmaking. The LD process is expected to expand rapidly in the next few years, and it can be safely said that the process, developed with new technical ideas, will be further perfected and will contribute much to the steel industry and national economy of Japan.

Frequency charts of chemical composition of killed steel intended for structural use: ladle analysis.



Employment Trends for Engineers

At the 125th Annual Meeting of the American Association for the Advancement of Science, JOURNAL OF METALS *listened-in while some leading authorities discussed the employment outlook for scientists and engineers.*

by J. J. Burke

ALTHOUGH the satellites are up, enrollments are down. Even though 30,000 engineers came from "nowhere" between 1954 and 1957, long range demands might even outrun the *theoretical* limit of supply, based on a distribution curve of abiltiy.

These and many other problems were aired at the Scientific Manpower Conference, held in conjunction with the 125th Annual Meeting of the American Association for the Advancement of Science, which took place in December in Washington, D. C. Among those participating were Clarence H. Linder, vice president, engineering, for the General Electric Co., William H. Chartener, economist with the McGraw-Hill Publishing Co., and Robley Winfrey from the US Bureau of Public Roads. Although the theme for the conference was *The Employment Situation for Scientists and Engineers in 1959*, discussion ranged far beyond these limits.

Supply and demand: short and long range views

For a solid year, since the first Sputnik soared into space, the need for more technical personnel has had almost daily attention from one source or another, all duly reported by the Nation's press. Nevertheless, last autumn, after a short period of softness in the job market due to the general business recession, Dr. Chartener reported that engineering enrollments dropped more than 10 pct. This indicates that general business conditions, rather than unsupported demand, dictate the short-term supply of manpower. However, he was quick to point out that enrollments and degrees granted are themselves quite unreliable as indicators of short-run supply; about 70,000 bachelor engineering degrees were conferred from 1954 to 1957, but employment of engineers in industry alone rose over 100,000 during that period. Mr. Linder added that at GE, one-third of their electrical engineers, half of their mechanical engineers, and two-thirds of their physicists majored in different fields at college. These two factors indicate that the supply of technical manpower is quite *flexible*: in the short run, you will get a man to fill the job *if* you are willing to pay the price.

The long range picture leads to one conclusion: we must utilize existing talent to better advantage. The problem, in perhaps its most pessimistic form, is stated by Mr. Linder: "Suppose we did achieve the maximum increase in the quantity and quality of competence available; there still remains the fact that the number of people endowed with the necessary mental capacity is a fixed proportion of the total population. There is a very real possibility that the demands of our complex civilization may outrun even the theoretical maximum of available competence indicated by the distribution curve of ability. What then? We shall have to farm better with what we have."

This rather frightening prospect was somewhat lightened by Mr. Winfrey, who discussed manpower requirements of the gigantic Federal Highway Program. Although one would naturally expect that this program would require huge reserves of engineering talent, Mr. Winfrey declared that recent significant advances in aerial surveying and mapping, plus adaptation of electronic computers to highway construction problems, have so increased an engineer's effectiveness, that only moderate increases will be necessary. These modern methods make it possible to do all work prior to actual construction without an engineer setting foot on the land.

Another aspect of this same problem is putting the right man on the right job. Mr. Linder took some time to describe the system that GE has developed to account for and marshal its human resources. A classification system was developed which took into account activities, fields of interests, and product fields. Each scientist and engineer then classified himself within this system, and the information was set up for mechanized data processing. This entire catalog of available talent is scanned every time an open position is to be filled. Here is at least one instance where a large organization is making full use of this great business asset—technical knowledge.

Salaries

On the subject of compensation, a similar note was struck by both Dr. Chartener and Mr. Linder. It was this: that while young engineers receive high starting salaries, competent engineers with, say, ten years experience are not compensated proportionally, and are, in many cases, paid less than their non-technical classmates. Mr. Linder attributes this to a ceiling arbitrarily imposed on compensation for purely technical contributions, above which managerial responsibility must be taken on. Most companies have raised this ceiling in recent years, but it is logical to expect that those that haven't done so are the ones complaining most acutely about the shortage of scientists and engineers.

Thus, what some might have regarded as a lot of talk a year or more ago *has* borne fruit; much of the confusion about supply and demand factors has been cleared away, and certain organizations are doing a great deal to make the most out of the resources they have.

THE AWAKENING DRAGON

A Staff-written Summary

Summarizing reports from Chinese and free world sources, JOURNAL OF METALS *presents a report on the industrial growth of Communist China during the last few years, as succeeding five-year plans seek to make use of the tremendous population and resource potential which could build China into a top-position industrial country.*

A SLEEPING giant, a slumbering dragon is a harmless thing, but an awakening colossus, a dragon fired with new strength surging in its body, is something else.

This dragon is China, with her teeming millions taking hold of the tools of industrialization developed in the western world. Perhaps the oldest country in the world, China stands today as the youngest, just beginning to realize her potential and feel the hot blood of nationalism in her veins.

Not only are 650 million persons awakening to these new impulses and being organized into vast industrialization schemes, but the natural raw materials of the country are more than adequate to satisfy any foreseeable needs of the future. Together with the USSR, China apparently lacks no mineral raw material, with the exception of industrial diamonds. In regard to coal alone, Chinese reserves were estimated some years ago to be the fourth largest in the world amounting to some 450 billion metric tons. The reserves are predominantly high-grade anthracite and bituminous coal; known coking coal reserves exceed 5 billion tons. Iron ore reserves were estimated some years ago to exceed 4 billion tons. These estimates must be considered to be more than conservative in the light of the fact that the country is only now being extensively explored geologically. So the dragon not only has the population, she also has the natural resources to sustain heavy industry.

The present day government in China was not the first to begin tapping the country's resources. The Japanese, during their occupation of Manchuria, did much to develop the iron ore and coal resources of the region, and built the large integrated steel works at Anshan. Dismantled by the Soviets after World War II, the plant has now been reconstructed. It is the largest in China, representing the mainstay of the country's present industrial capacity. The plant's 1958 crude steel production is estimated at 4.4 million metric tons with pig iron estimated at 3.3 million. The latest achivements of Soviet technology have been used in this plant with Soviet engineers brought in to supervise reconstruction. It now includes six blast furnaces, four open-hearths, two sheet mills, a new plate mill, eight additional rolling mills, a seamless tube mill, three refractory plants, and a large ore-dressing plant at the nearby Takushan deposits. Anshan's No. 10 blast furnace, the largest in China, was completed last November; it is claimed that all its equipment was made in China. Of its open-hearth furnaces, the first built has a capacity of 660 metric tons.

Two other previously existing plants are the Shanghai Iron and Steel Works and the nearby Maanshan Iron Smelting Plant. These have been brought back into service and modernized to supply raw materials for industry. Maanshan has six or seven small blast furnaces while the Shanghai Iron and Steel Works includes bessemer converters, open-hearth furnaces, rolling mills, and a seamless tube plant. Its crude steel production is probably on the order of 700,000 metric tons.

A number of other existing works were inherited by the present government. These have been modernized and expanded. The Chungking plant is probably an example. It is now reportedly producing 600,000 tons of steel per year in a new bessemer converter plant.

New steel plants

But the present industrialization program in China is not merely confined to modernization and rebuilding. Construction has gone ahead on two new inte-

grated works: one at Wuhan, another at Paotow. Each will produce 1.5 million tons of steel annually when construction is completed in 1962.

The Wuhan plant commissioned its first blast furnace on Sept. 13, 1958. Built with Soviet help, the furnace is claimed to have a capacity of 2000 tpd (metric). When the sintering plant goes into operation, daily blast furnace capacity is expected to reach 2500 tons. Wuhan draws its ore from the Tayeh iron mine which is expected to produce 900,000 tons of iron ore for the Wuhan's No. 1 blast furnace alone. Wuhan also has at least one coke-oven battery of Soviet design and is building nine open-hearth furnaces designed and equipped by the USSR. Their first 70-ton open-hearth furnace was commissioned late last year. Experimentation in producing high-grade steel in ordinary open-hearth furnaces is being carried out under East German supervision.

The second major integrated plant—Paotow Iron and Steel Works—has 13 construction projects underway. The facilities at Paotow will include a fully automatic blast furnace, open-hearth furnaces, and a coking battery.

Another large plant, for which ground has only recently been broken, is the Anyang Iron and Steel Works in Honan Province. When completed, crude steel capacity will be 800,000 tons, pig iron capacity 700,000 tons, and rolled steel capacity 500,000 tons. Main products are to be medium and light sections, and plates. There are local deposits of rich iron ore and coking coal.

Many other plants have been mentioned in recent press reports. One is a 200,000-ton plant at Peking for the production of rolled steel. Another, which appears to be in a long range plan, is the construction of an 800,000-ton steel plant in Heilungkiang (northern Manchuria).

But in an unindustrialized country lacking capital resources, construction of large industrial plants must indeed be limited and highly dependent upon help from outside sources. Such help, in this case, comes from the USSR and the countries of eastern Europe. But the leaders of China are demanding increasing quantities of iron and steel for their industrialization program. A partial answer has been found during this past year.

Pot-belly furnaces

History is said to repeat itself, and perhaps the ancient Celtic iron masters of Europe would indeed find themselves at home in today's China.

China is building furnaces on the same order that patriotic citizens in the US raised Victory Gardens during World War II. "A furnace in every backyard" seems to be the slogan. True, this will create impressive statistics, but statistics do not necessarily reflect quality. China's National Conference on Small Blast Furnaces announced last year that 30,000 small iron-smelting furnaces had been built during the first seven months of 1958. Radio Peking describes many of these furnaces as "designed by peasants and made of empty gasoline drums or iron caldrons lined with fire clay to withstand high temperatures. Raw materials are mined locally. Furnaces are charged with crushed magnitite of high iron content, limestone, and coke; they yield a heat of iron in about 3 hr. Peasants with no knowledge of iron smelting can master the technique in the course of one heat."

A typical furnace resembles a pot-bellied stove familiar to the cracker barrel set at the turn of the century. It stands about 10-ft high and tapers off toward the bottom from a 4-ft diam at the center. We are told by Peking Radio that a furnace with less than half a cubic meter capacity can turn out 16 metric tons of pig iron a day. If these figures are correct, extensive blower systems must be raising furnace heat to extremely high temperatures.

But rose beds always contain thorns, and the Chinese admit a problem of two in their victory garden system. Not only does the quality of pig iron vary from heat to heat in the pot-belly furnaces, but it is seldom high enough for the iron to be used as feed stock for steelmaking furnaces due to the sulfur content. This iron may, on the other hand, be suitable for low-quality castings.

Industrialization goals

Believing industrialization to be the key to the future, the leaders of Communist China have set their goals high. Their first major objective, aside from specifics in their five-year plans, is to surpass the UK in industrial production. This would place China in a high-ranking position among the countries of the world.

Elmer W. Pehrson, lecturer in mineral economics at Columbia University, has remarked that the Chinese leaders set a goal to overtake the UK in industrial production by 1973. Judging by the progress made in 1958, he sees no reason why this may not be possible in 1963. As one example, he cites Chinese coal production in 1958 as being on the order of 200 million tons, only slightly below that of the UK.

From China, construction figures in general are given out as freely as bus transfers. As announced by the China Trade Report in April 1958, the 1957 production was as follows: 5,847,000 metric tons of pig iron, 5,235,000 tons of crude steel, 4,470,000 tons of rolled steel, and 123,900,000 tons of coal. Capacity was to increase in 1958 by the following amounts: 1.88 million tons of pig iron, 1.17 million tons of crude steel, and 0.76 million tons of rolled steel.

The Chinese Politburo, meeting in the summer of 1958, doubled the crude steel target figure of the previous year, setting the goal at 10,700,000 metric tons. Last December the New China News Agency triumphantly announced that the 1958 production target of 10.7 million metric tons of steel had been exceeded, and it was possible that 11 million tons was likely to be the year-end figure. Whether or not there has been any confusion between steel and iron production statistics is impossible to say, but the initial 1959 target for steel is 18 million tons.

And where to?

After thousands of years of dynastic and republican rule, during which time China has maintained a dominantly agricultural status, the Communist leaders are seeking to revamp the nation into a highly industrialized country within a few decades. With the current volume of propaganda flourishing, one may easily overestimate the achievement of short range production targets and the success of the mud blast furnace project. But China has the resources and the population. She also has strong leadership which is capable of regimenting these potentials into clearly defined channels. If we are to presume stability of the present government on the Chinese mainland, the potentials of the awakening dragon may some day be achieved.

BESSEMERIZING THE BLAST-FURNACE BATH

Utilization of ironmaking raw materials of varying grades has been a postwar headache of the Japanese steel industry. Bessemerizing of the blast-furnace bath was designed for elimination of sulfur and chromium, but experiments indicate its possibilities stretch far beyond this.

Based on a paper by

金森九郎

Kuro Kanamori

EXPERIMENTS in bessemerizing the bath of the blast furnace were undertaken in order to make full use of the raw materials available to the Japanese iron and steel industry. This process could be employed to produce low-silicon, low-sulfur, high-manganese basic pig iron at high temperatures from ores of widely varying quality.

Ten years ago, when the raw material situation was most acute, bessemerizing experiments were begun at the Institute of Industrial Science of Tokyo University. In 1951-52 a joint research project with Yawata Iron & Steel Works was undertaken, making use of a 3-tpd test blast furnace at Yawata. Still later a 1-tpd blast furnace was constructed at the Institute of Industrial Science.

In the blast-furnace bessemerizing process, oxygen-enriched air is blown directly into the metal bath, thus making this previously dormant area of the furnace an active refining zone. In the normal converter process, the burst-out of waste gas from the mouth of the furnace is utterly lost in the air, but in the new process the waste gas runs up the shaft of the blast furnace and is utilized for pre-heating the charge; therefore, it may be considered to be an enclosed converter. Furthermore, due to the thick molten slag cover and the hot bed of coke on the bath, there is no spattering loss of metal and little oxidation loss of iron, such as is common in the case of the converter process. Above the tuyere line there are normal blast-furnace reducing operations, but below that line in the bath, converter-type oxidizing reactions are taking place.

An additional advantage of bessemerizing the blast-furnace bath lies in the realm of temperature control. Until recently there has been no means to control the hearth temperature other than to change the blast temperature or the coke ratio. Such methods are neither effective nor efficient, but bessemerizing the bath of the blast furnace is a direct process of bath temperature control, and effective results can be achieved in an instant.

Test blast-furnace design

The 3-tpd blast furnace, shown in Fig. 1, was lined with carbon brick below the slag line. The 1-tpd experimental furnace had a high-frequency coil set in the bottom of the hearth in order to compensate for the heat loss. The secondary current, which was induced by this coil, made the use of carbon brick impossible, and fireclay brick of good quality was used.

The furnace had four ordinary tuyeres plus one specially designed tuyere, inclined at about 60°, Fig. 2. Through it a pipe could be inserted for bessemerizing, sampling, and injection of powdered materials into the bath of the furnace. For bessemerizing, the cock *a* was first opened, thereby sending in a blast. Next the end cover *b* was opened, and the lance inserted, forcing oxygen-enriched compressed air into the furnace. After the temperature was raised to the desired level, oxygen was cut off, the lance pulled out, end cover *b* closed, and the blast cock *a* shut.

To conduct the bessemerizing process, rapid changes of hearth temperature must be watched for constantly; therefore, a slant, top-closed carbon pipe *c* was set in the bottom of the hearth. Carbon has such good heat conductivity that its top-end temperature shows distinctly rapid changes of molten-metal temperature. For this reason, hearth temperature can be checked at the outer end of the carbon pipe by optical or radiation pyrometer.

Equipment for preparing raw materials includes a crusher and screen. Coke is reduced to the 10 to 20 mm size range, while ore and limestone are slightly finer—3 to 10 mm.

For the 3-tpd furnace, a 50 cu m per min Roots blowing engine is used, while the blower for the 1-tpd blast furnace is rated at 14.2 cu m per min. Cowper-type hot stoves are used on the larger furnace, while a recuperator-type stove with oil and gas burners is used on the smaller furnace. Before entering the furnace, the blast on the latter passes through an electric heater which is able to control temperatures to within 10°. Blast temperatures were maintained at about 600°C.

3-tpd furnace operations

Four campaigns were run on the 3-tpd blast furnace at the Yawata works. Pig iron produced during normal operations contained 3.6 to 3.8 pct C, 1.0 to 1.3 pct Si, 1.0 to 1.5 pct Mn, and 0.05 to 0.06 pct S. Bessemerizing reduced the silicon content and resulted in pig iron of the following composition: 4.0 to 4.2 pct C, 0.5 to 0.8 pct Si, 1.5 to 1.8 pct Mn, and 0.01 to 0.02 pct S. The basicity of the slag was raised to 1.5 in order to increase desulfur-

KURO KANAMORI is a professor of the Institute of Industrial Science, University of Tokyo, Japan.

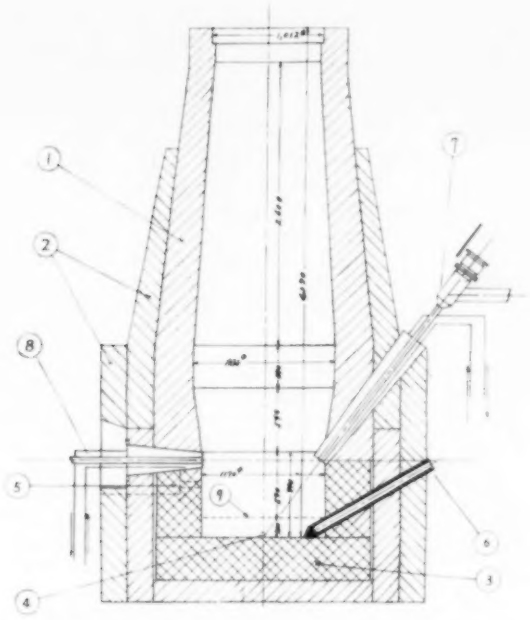


Fig. 1—Construction of the 3-tpd experimental furnace: 1, chamotte brick; 2, isolite brick; 3, carbon brick; 4, tap hole; 5, slag notch; 6, temperature measuring tube; 7, slanted tuyere for bessemerizing; 8, ordinary tuyere; 9, bottom line of ordinary blast furnace.

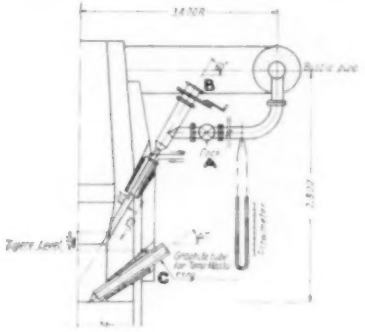


Fig. 2—Design of the special tuyere for bessemerizing.

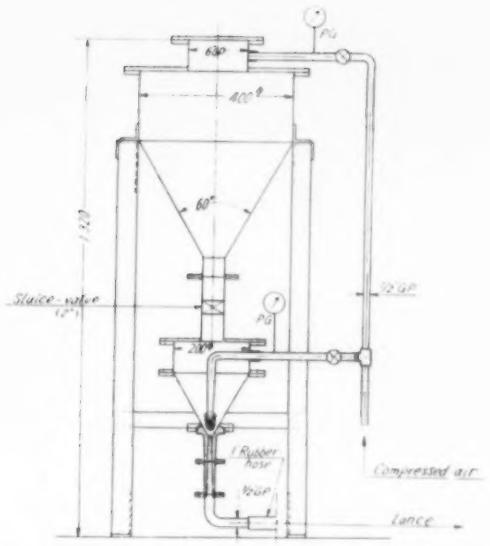


Fig. 3—Injector-type feeder designed to introduce powdered material directly into the bath.

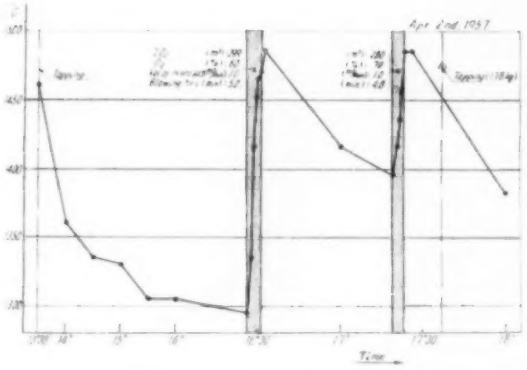


Fig. 4—Plot of temperature changes during bessemerizing in the 1-tpd blast furnace.

ization, but, in spite of such high basicity, the fluidity of the slag was good. While an increase of iron oxide in the slag might have been expected from the bessemerizing process, it actually decreased because of the reducing action of the bed of coke on the high-temperature bath.

In the course of these experiments, three important operations besides bessemerizing by oxygen-enriched air were introduced, namely: sampling of molten slag and metal directly from the bath, injection of such alloying materials as Fe-Si, Fe-Mn, or such slagging materials as lime directly into the bath, and blowing carbon dioxide or nitrogen with powdered iron ore or atomized water (not steam) as coolants. These experiments looked toward a method of rapidly regulating the composition and temperature of the bath.

To check blast-furnace operation, a specially devised sampling pipe is inserted through the slanted tuyere. It can be used to ladle up a slag or metal sample directly from the blast-furnace bath at any time.

An injector-type feeder of powdered materials, Fig. 3, was designed and tested for the purpose of injecting powdered materials directly into the molten slag or metal. Thus, there arose the possibility of rapid and direct control of slag and metal components in the hearth, which had been quite impossible by former blast-furnace practice.

Since it is not possible to observe the lance in the bath, it proved difficult to maintain it at the most effective point during the bessemerizing operation. However, the back pressure gage does give an indication of whether the lance is touching the molten iron or not, and the ½-in. refractory-coated steel lance is fed in accordingly. Lance consumption amounts to between 5 and 6 cm per min of bessemerizing.

1-tpd furnace operation

Beginning in 1955, campaigns were run on a 1-tpd blast furnace at Tokyo University. During these campaigns we tried to solve the following problems: to find durable hearth-lining materials, to establish normal running conditions for such a small test furnace, to determine the special bes-

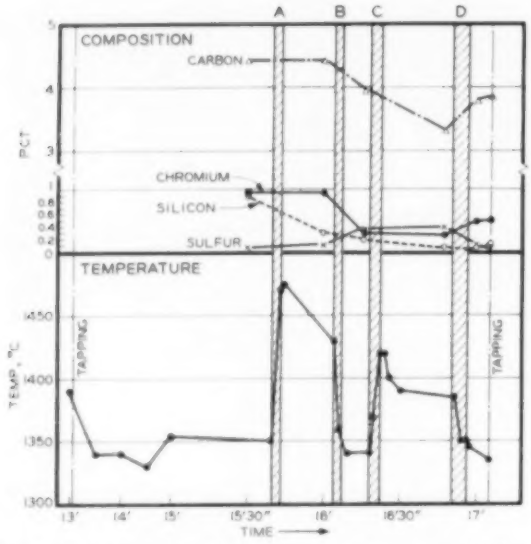


Fig. 5—Typical example of what happens to temperature, carbon, chromium, silicon, and sulfur during bessemerizing. Blowing in four periods, A-D, conformed to the following specifications:

	A	B	C	D
Total O_2, cu m	1.5	0.5	2.5	0.83
O_2, pct	60	21	60-70	21
Volume of mixed gas, cu m per min	1.0	0.8	1.0	0.72
Blowing time, min	2½	3	4	5½
Ore, kg		25		
CaO, kg		5		7
FeMn, kg				10
Al, kg				1
CaF_2, kg				7

semerizing conditions suitable to the furnace, and to establish the working conditions for the elimination of chromium in the bath.

Desiliconizing

Bessemerizing increases the metal temperature in the hearth by the oxidation of silicon in the molten metal. Under ordinary working conditions the bath temperature of such small blast furnaces is below 1400°C. By blowing oxygen-enriched air into the bath for about 5 min every 4 to 6 hr, hearth temperature can be increased to as much as 1500°C.

The temperature rises 15°C per min during bessemerizing on the 3-tpd furnace, Fig. 4, and 40° per min on the 1-tpd furnace. The oxygen concentration used ranges from 50 to 70 pct, with a pressure of 3 kg per sq cm on the 3-tpd furnace, and 2 kg on the 1-tpd furnace. The quantity blown is 2.5 cu m per min on the former, and 0.8 to 1.1 cu m per min on the latter furnace.

Sulfur elimination

One of the original objects of developing the bessemerizing process in the blast furnace was to promote desulfurization by raising the hearth temperature through oxidation of silicon and by maintaining a highly fluid basic slag. This object was attained during an early phase of the experiments. During the normal operation of the 3-tpd blast furnace, sulfur content of the metal was from 0.1 to 0.2 pct when using iron ore containing 2 pct S. Bessemerizing raised the tap temperature to between 1400° and 1450°C. The slag basicity was increased to 1.5 by blowing in suitable powdered fluxes. The result was that the sulfur content of the metal was reduced to 0.01 to 0.02 pct. The manganese content of the metal became higher than normal pig iron—1.7 to 2.0 pct.

Chromium elimination

Bessemerizing the blast furnace may make it possible to charge high-chromium laterite ores. To eliminate chromium from the metal bath, it is essential to keep the hearth temperature at about 1350°C while oxidizing with the lance. For this purpose, coolants must be used with the bessemerizing gas; atomized water (not steam) or powdered iron ore (under 10 mesh) have been used in experiments.

In the 1-tpd blast furnace, chromium ore was charged in order to maintain a pig iron content of about 1 pct Cr. For bessemerizing, air enriched to as much as 70 pct O_2 was blown at the rate of 0.8 cu m per min; it carried atomized water to the extent of 0.8 liters per min. The total oxygen blown was 60 cu m per metric ton of metal. While chromium was brought down to 0.3 pct, these tests resulted in too great a drop in carbon and showed an increase in sulfur. Also, the fluidity of the metal was not good enough for practical operations.

Tests were also undertaken at the same blowing rate and with 20 kg of powdered iron ore per min blown in simultaneously. In the gas mixture, nitrogen or carbon dioxide was substituted for air. The drop in the hearth temperature was about 50°C, and chromium in the metal was removed much more effectively—to 0.2 pct. In one example 85 pct of the chromium was removed when blowing a total of 58 cu m of oxygen per metric ton of metal, and the reduction in carbon content was quite small. However, the problems of increased sulfur and poor metal fluidity from over-oxidation were not solved. But this was met by blowing powdered deoxidizer and desulfurizer, such as Fe-Mn, aluminum, lime, and calcium fluoride, into the bath. Sulfur was reduced from 0.4 to 0.04 pct. But at the same time, chromium returned to the metal from the slag and increased from 0.2 to about 0.5 pct, Fig. 5.

Thus, this oxidizing method does not seem to provide effective means of chromium removal in the furnace bath under the existing reducing atmosphere. We now think it may be better to remove chromium outside of the furnace after tapping by the same procedure: oxidizing and keeping the temperature low.

Conclusions

About 600 years have elapsed since the first blast furnace was constructed. No fundamental improvement has been made since then, even though the capacity has been enlarged up to more than 1500 tpd and the mechanical and accessory parts have been improved considerably. Direct control of hearth temperatures and slag and metal components of the bath should be a step toward the further improvement of blast-furnace operation.

In the future, resources of good-quality ores may be exhausted, and we may have to utilize ores with a high content of impurities, such as sulfur, titanium, chromium, and arsenic, which have hitherto been considered unworkable for the blast furnace. To solve this problem, much work has been done. We have taken up bessemerizing the bath of the blast furnace for this purpose, and we are continuing with further experiments.

SLAG RECOVERY AT YAWATA WORKS

Economics of steel production in Japan are such that this large producer has found means of utilizing some two-thirds of its open-hearth slag.

Summarized from an article by
Kamekichi Wada

IN one recent year, Yawata works produced 2,930,000 metric tons of ingot steel, generating in the process 406 lb of open-hearth slag per metric ton of steel, amounting to a total of 594,500 metric tons of slag. This is quite a bit of material! But thanks to techniques developed at this works, 378,000 tons or 64 pct of this slag was put to good use. The various uses are shown in Table I.

Slag beneficiation

With the exception of slag for land fill, all slag generated in the open-hearth shops is sent to the slag beneficiation plant in a cinder car. Fig. 1 is a flow sheet of this plant. Hot slag is dumped into the yard of the plant, crushed to −8 in. with a skull cracker, and scrap steel and brick are sorted out by hand.

Slag is then crushed to −2⅝ in. in four jaw crushers and screened with a trummel into three fractions: −⅜ in., ⅜ to ⅞ in., and ⅞ to 2⅝ in. Most of the −⅜-in. fraction is sent to the sinter plant as raw feed, but some is held for magnetic separation; Fig. 2 is a flow sheet for this latter operation. The ⅜ to ⅞-in. fraction is used as bedding material on the sintering machine, and the ⅞ to 2⅝-in. portion is charged directly into the blast furnace. Fig. 3 shows this screened slag being loaded for transfer to the blast furnace.

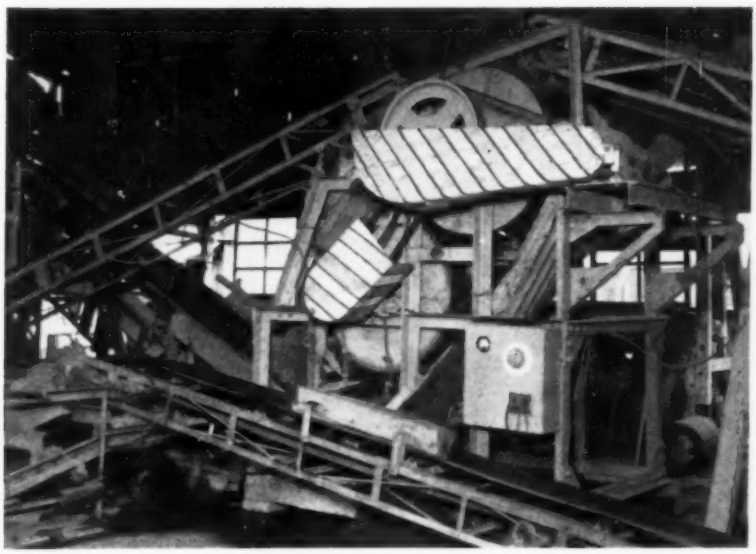
Any of the previously sorted steel scrap that is over 20 in. is again crushed, and then all scrap is charged into the open hearth. Scrap brick are used as land fill.

Magnetic separation

Slag under ⅜ in., not used as sinter feed, is separated on a Harada-type ac magnetic separator, which can handle 55 tons per hr. Fines from this step are separated on a ¼-in. vibrating screen, with the oversize, called Granular Iron A, being sent to the blast furnace. Undersize, or −¼ in., is again magnetically separated, and the fines from this step, called Granular Iron B, are sent to the sinter plant. Tailings from this step are mixed with other tailings.

Primary tailings from the first magnetic separation are screened, oversize is crushed, and submitted to another magnetic separation. Fines here join the primary fines, and tailings are separated into plus and minus ⅛-in. fractions, undersize going into

KAMEKICHI WADA is a director of the Yawata Iron & Steel Co. Ltd., and the director of the Technical Research Institute of the Yawata Iron & Steel Co.



Harada-type ac magnetic separator used for −⅜ in. slag.

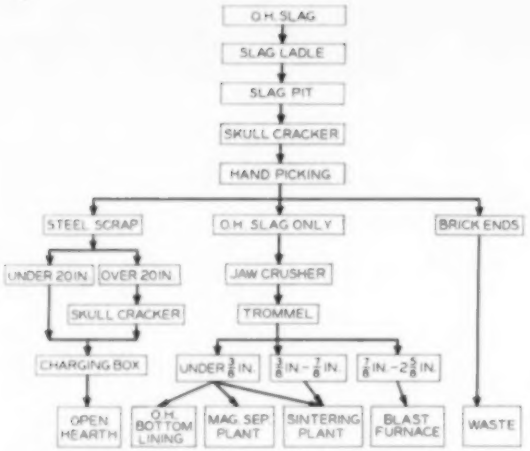


Fig. 1—Flow sheet for the slag beneficiation plant, which receives all slag generated in the open hearth-shops.

Table I. Uses of Open Hearth Slag

Kind	Use	Amount, Metric Tons	Distribution, Pct
Screened slag	blast furnace	226,200	38.1
	sintering	70,800	11.9
	open-hearth bed	16,200	2.7
	cement	6,800	1.1
	synthetic dolomite	2,700	0.5
	fertilizer	5,000	0.8
Granular A	blast furnace	7,000	1.2
Granular B	sintering	14,700	2.5
Scrap steel recovered	open hearth	28,700	4.8
Waste	land fill	216,400	36.4
TOTAL		594,500	100.0

fertilizer, dolomite and cement, and oversize being used for land fill.

Properties of open-hearth slag

Slag for blast-furnace use: In 1956, 214 lb of open-hearth slag were charged per metric ton of pig iron produced, for a total of 226,200 metric tons. This slag had the following size distribution and composition:

+3 In.	3 to 2 In.	2 to 3/8 In.	−3/8 In.
1.8 pct	24.2 pct	66.8 pct	7.2 pct

Composition, pct:			
Total Fe	25.5	Mn	5.4
FeO	24.5	S	0.18
SiO_2	13.1	TiO_2	1.3
Al_2O_3	3.6	P	1.1
CaO	30.0	Cu	0.018
MgO	8.2	Cr	0.18

Slag for sinter plant use: Total production of sinter in 1956 was 1,128,000 metric tons, corresponding to 34.4 pct of the ore charged to the blast furnace. About 66 lb of slag was used as sinter for each ton of pig produced, so the total slag consumption per metric ton of pig iron is 280 lb. The maximum addition is figured at 30 lb in order to prevent build-up of phosphorus and chromium in the pig iron. Size and composition of slag used for sintering is as follows:

	3/8 In.	3/8 to 1/4 In.	1/4 to 1/16 In.	−1/16 In.
For sintering	4.5 pct	38.5 pct	21.3 pct	35.7 pct
For bedding	68.3 pct	20.5 pct	4.7 pct	6.5 pct

Composition, pct:			
Total Fe	26.8	CaO	23.4
SiO_2	13.3	TiO_2	1.2

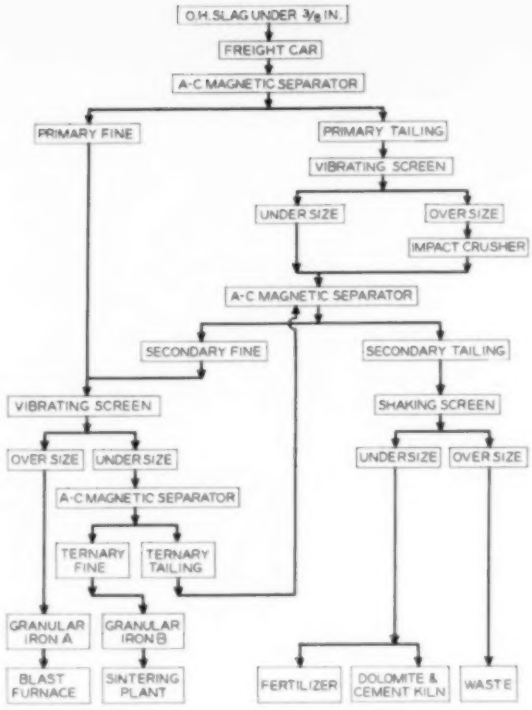


Fig. 2—Flow sheet for the magnetic separation plant.

Slag used for cement: Yawata produced 116,700 metric tons of clinker during 1956 which, along with 6800 metric ton of slag, was used for production of cement.

Slag for synthetic dolomite: About 28,500 metric tons of synthetic dolomite were produced in 1956, of which 2700 metric tons was open-hearth slag.

Slag for iron-bearing fertilizer: The elements contained in crushed slag tailings were found to be remarkably effective for rejuvenation of overworked rice paddy soils. In 1956, 5000 metric tons of slag were consumed for this purpose.

Slag recovered for Fe: Granular Iron A, containing 62.7 pct Fe, amounted to 7000 metric tons in 1956, while the B grade, 55.4 pct Fe, provided 14,700 tons. Size distribution was as follows:

Granular Iron	+2 In.	2 to 5/8 In.	5/8 to 3/8 In.	3/8 to 1/4 In.	−1/4 In.
A	20.5	33.0	27.3	15.6	3.6

Granular Iron	+1/4 In.	1/4 to 1/16 In	−1/16 In.
B	9.1	59.2	31.7

Scrap steel: Scrap steel from the slag beneficiation plant is crushed and charged into the open hearths. The scrap recovered from the slag in 1956 was 28,700 metric tons or 19.8 lb per metric ton of ingot steel.

Conclusions

Performance and operation of the blast furnaces at Yawata works has been improved year by year due to beneficiation of raw materials, not only iron ores, but also open-hearth slag. Through the beneficiation of open-hearth slag we are able to decrease the coke rate and gain many advantages from its new utilization.

DISPERSION STRENGTHENED ALLOYS:

The Possibilities for Light Metals

A Review in Two Parts by Claus G. Goetzel

A state-of-the-art exclusive for JOURNAL OF METALS *readers, written by one of the well-known metallurgists in the field.*

DURING the past decade the process of strengthening metals by means of a highly dispersed hard phase has gained widespread attention. Of particular interest is the fact that in several metals, notably of the light metal group, remarkably stable high-temperature properties can be obtained thanks to the strengthening action of the dispersed phase. An excellent report of results achieved with dispersion alloys of copper, nickel, molybdenum, and other metals suitable for high-temperature applications was given by Grant and Preston[1] at the AIME Powder Metallurgy Symposium in 1956. Since that time, development work has continued on these metals as well as on cobalt, columbium, nickel, and cobalt alloys, steels, and others. The present discussion concerns itself primarily with the dispersion strengthening of aluminum and other light metals, because more data are available from which certain conclusions can be safely drawn. Attention will be given to the potentials of these materials in actual engineering applications.

Dispersion strengthening—fundamentals

Various investigators have considered the dispersion strengthened alloys, as exemplified by the aluminum powder metallurgy products, as a new class of engineering materials whose excellent high-temperature properties are derived from an extremely fine size and uniform distribution of the hard phase in a metallic matrix.[2, 3]

A comparison of the 500°C (930°F) tensile strength between a typical oxide dispersion-strengthened aluminum alloy of the SAP type and heat-treated wrought aluminum alloys, such as alloy 18S-T61, shows an advantage of the former to the extent of over 150 pct. Equally spectacular are the creep, stress-rupture, and fatigue properties in the 300° to 500°C (570° to 930°F) temperature range, which exceed those of heat-treated wrought alloys by substantial margins.[4,5] On the other hand, other properties such as thermal and electrical conductivity, thermal shock resistance, or hot-working properties are predominantly metallic in character. Thus, these dispersion alloys with the metal matrix as predominant phase, appear to be distinct from the new class of cermet materials, and rather closely allied to the conventional age-hardening alloy systems.[1]

The dispersion strengthening process

The normal process of precipitation or age-hardening occurs when a supersaturated solid solution precipitates its excess solute. The process is favored in alloy systems with appreciably greater solubility for the solute at elevated temperatures than at lower or ambient temperatures. The precipitate effects strengthening of the structure by a mechanism that has been explained by Geisler[6] to be primarily based on coherency strains set up in the matrix by the precipitated particles. Dispersion hardening apparently plays only a minor role in this process. The process may, however, be appreciably modified if a third constituent is added to the system which results in the precipitation of the compound that is insoluble in the solvent.

Such precipitate would have little tendency to coalesce, and would retain its strengthening effects on the matrix even after extensive heat treatment. This type of reaction is now commonly referred to as dispersion strengthening, but has also been called interference hardening.

One of the principle differences between the strengthening effected in precipitation hardening systems and dispersion-hardening systems lies, undoubtedly, in the *nature* of the hard phase. Alumina is virtually insoluble in the aluminum matrix over the relatively narrow span of low temperatures dictated by the melting point of aluminum. Hence, no dissolution effects, as in overaging, are encountered in this system. This favorable aspect may be partly or fully lost in other systems, where solubility relations between the dispersed phase and the matrix are different, or where diffusion processes are more dominant, due to raised sintering and consolidation temperatures. Also, less refractory compounds, such as $FeAl_3$, while recently reported[7] to be most effective as a dispersion hardener for aluminum, may lose their strengthening power at higher temperatures. This is due to increased diffusion and solution rates, similar to the mechanism of coarsening, and solution of precipitates in overaged alloys.

While chemical stability, refractoriness, and high hardness are basic properties required in the dispersed phase, there are other important factors of no less significance to the proper functioning of the mechanism of dispersion strengthening. Of these, the size of the hard particles and the distance between them appear of paramount importance. Yet, ductility of the matrix metal, bond strength and wettability between the two phases, shape of the hard particles and its possible effect on the distribution of dislocations in the matrix, inhibition of recrystallization and grain growth by barriers set up by the hard phase, and the existence of a large measure of stored energy in the fabricated dispersion alloy products, are all factors of importance which must be considered in any study of the mechanism.

In the classic dispersion alloy system, Al-Al_2O_3, there can be little question about the stability and

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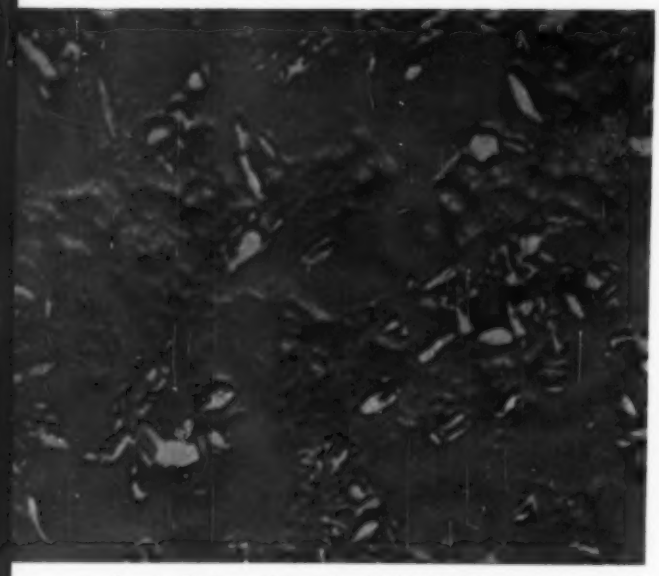

Fig. 1—Electron micrograph of Al-Al_2O_3 alloy extrusion M-257 containing 6-8 wt pct oxide. X20,000. Courtesy of N. J. Grant.

hardness of the dispersed oxide phase. Although there is some doubt about the modification of Al_2O_3 present in SAP, it is stable up to the melting point of the aluminum, and its hardness is still very high at this temperature. In fact, its loss in hardness with temperature is much less than that of the matrix. Seith and Löpmann[8] made the observation that the reason for the relatively high thermal and electrical conductivities of the SAP products containing about 10 to 11 pct oxide, may lie in the non-stoichiometric composition Al_4O_7 of the oxide phase associated with an excess amount of aluminum. Although the exact composition of the compound has not been reported (Gregory and Grant[4] had found by X-ray diffraction the existence of gamma-Al_2O_3 when the disperse phase had been extracted by HCl solution from solid SAP and APM), Irmann emphasizes the advantages of less sluggish compound than Al_2O_3 as far as the sintering and consolidation process is concerned.[9]

The principle requirements of the dispersed phase, such as low solid solubility in the matrix metal, low diffusion rate of alloying elements in the dispersed phase to retard coarsening, and a high solidus temperature, are also met by several intermetallic compounds. Towner has recently shown that $FeAl_3$ and $CrAl_7$ are effective dispersoids in relatively coarse atomized powders that are subsequently consolidated by extrusion.[7] Busk and Leontis have reported strengthening effects by the precipitation of a fine dispersion of an Al-Zr compound completely insoluble in solid magnesium matrix metal.[10]

Theory of dispersion hardening

The prevailing theory of dispersion hardening, as advanced by Orowan,[11] Mott,[12] and by Fisher, Hart and Pry,[13] relates strength to particle spacing and the role played by dislocations in the immediate vicinity of the dispersed phase particles. The dislocations of special significance appear to be those that, after working and upon annealing, are prevented from annihilation by a locking action of the hard particles. Dislocation loops generated by cold work near the hard particles appear to be rather stable.

Irmann, von Zeerleder, and Rohner,[14] applying Rohner's[15] theory of strengthening in age hardened Al-Cu alloys to flake aluminum powder extrusions containing Al_2O_3 dispersions in an aluminum matrix, established a direct relationship between the elastic limit of the dispersion alloy and the average distance between the dispersed particles. This average distance was assumed to be approximately equal to that between the oxide skins on the flake particles of the original powder. Lenel and co-workers established fairly good agreement between the elastic limit calculated according to Rohner's relationship, and the 0.02 pct room-temperature proof stress measured on extrusions of two different flake powders.[5]

Gregory and Grant,[4, 16] using the electron microscope, measured the distance between the hard oxide particles found dispersed in the aluminum matrix on extrusions containing 13 pct Al_2O_3, Fig. 1. They applied their data to the theories of dispersion hardening by Orowan,[11] Gensamer and co-workers,[17] and Dorn and co-workers,[18] and found that the linear relationship between yield strength and the logarithm of the mean free path, as established between carbide particles in ferrite by Gensamer, could not be satisfied. Neither could the logarithm of the volume or planar mean free path between $CuAl_2$ particles in alpha solid solution of Cu in Al, as established by Dorn, be satisfied. Instead, a straight line relationship was found between the strength and the reciprocal of the interparticle spacing, indicating agreement with the dispersion-hardening theories of Orowan and Rohner in the range of interparticle spacing encountered in their extruded products, Fig. 2.

Lenel and co-workers established a straight line relationship on Al-Al_2O_3 alloys between tensile strength at room temperature and at 400°C (750°F) vs the logarithm of the thickness of very fine flakes, Fig. 3. Thus, they apparently confirmed the relationship developed by Gensamer.

Role of interparticle spacing

Based on the work reported to date, strengthening becomes pronounced if the average interparticle spacing is well below 1 μ, preferably in the order

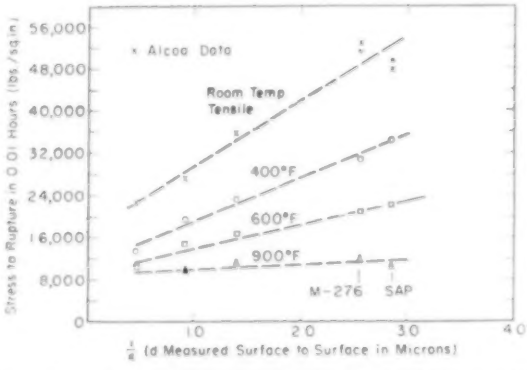

Fig. 2—Stress vs reciprocal of average spacing between oxide particles in Al-Al_2O_3 alloys for room temperature tensile strength and 0.01 hr rupture life at 400°, 600°, and 900°F (205°, 315°, and 480°C).[4]

of 0.2 to 0.5 μ, although spacings of 1 μ and more will have a certain effect.

The aforementioned relationships of strength and distance between the hard particles are primarily valid for low temperatures, where plastic deformation takes place predominantly through the mechanism of slip. At higher temperatures, the usual form of slip loses its dominance and the role of the grain boundaries becomes important in the deformation process. Grant and co-workers have postulated that the strengthening and immobilization of grain boundaries by the hard phase may directly contribute to increased creep resistance and long time stability at relatively high temperatures.[1, 19] They also suggest that the resistance of SAP to deformation at elevated temperatures is due to the ultra-fine flake sizes of the original powder (approximately 10^{-4} cm). The material possesses about the minimum particle or crystallite size in which recrystallization and grain growth are prevented by the fine oxide barriers. It was found that hardness and tensile strength are little increased by cold work of SAP, up to a maximum of 29 pct. Efforts to recrystallize the as-extruded or the cold-worked SAP were unsuccessful, but recovery upon high-temperature annealing was noticed.

Strain energy storage

In interpreting these results, Grant and Preston[1] suggest that energy equivalent to a large amount of cold work already exists in the extruded Al-Al_2O_3 structure, as shown schematically in Fig. 4. By extrapolating a room-temperature curve of strength vs oxide content to 0 pct Al_2O_3, a tensile strength value of 19,000 psi was found which is well in excess of that for pure annealed aluminum. Their findings, that the plastic work stored in the matrix during extrusion is difficult to recover by annealing, and that recrystallization is not in evidence up to the melting point of the matrix, indicate that the greater thermal stability of the SAP-type of dispersion alloy is mainly caused by the high resistance to boundary migration.

Recently Lenel and Nelson[20] have attempted to separate the effect on the strengthening of the very finely dispersed second phase from the contributions made by the immobilization of the grain boundaries and the storage of strain energy during extrusion. They found that a very coarse-grained and relatively strain-free structure can be produced in aluminum powder extrusions by severe cold working and high-temperature annealing. Extrusions of a relatively coarse flake powder (MD 2100, 0.8 μ flake thickness) increase their hardness and strength through cold working. However, these properties decrease abruptly when the extrusions are heated above recrystallization temperature and level off at higher temperatures. A concomitant gradual increase in elongation with annealing temperature was also noticed. The recrystallization temperature range was found to depend on the amount of cold work applied. Even the recrystallized material was found to be much stronger than commercially pure aluminum, both at room temperature and at 400°C (750°F).* These results indicate that for the relatively coarse powder used, the strengthening effects of the very finely dispersed second (Al_2O_3) phase are predominant.

* 29,000 psi vs 13,000 psi, and 8000 psi vs <1500 psi, respectively.

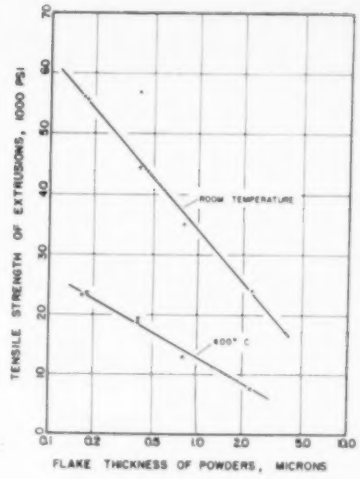

Fig. 3—Tensile strength of aluminum flake powder extrusions as a function of the powder flake thickness plotted logarithmically.[2]

Ansell and Weertman extended the study of the same type of material by investigating the creep properties.[21] As-extruded MD 2100-base Al-Al_2O_3 alloy shows an approximately steady-state creep in which the creep rate depends exponentially on the applied stress. The activation energy of creep is approximately 150,000 cal per mole. The recrystallized alloy, on the other hand, shows at 600°C (1110°F) a steady-state creep rate of less than 10^{-8} min^{-1} at 2900 psi, and no steady-state at even higher stress levels of 400° and 500°C (750° and 930°F). A lower tensile strength of the recrystallized material, as compared to the extruded alloy, is attributed to stress concentration effects. Ansell and Weertman explain this unexpected behavior by postulating that in the recrystallized material, the fine dispersion eliminates the sources of dislocations rather than inhibiting the movement of dislocation loops created at the sources.

The previously cited work by Seith and Löpmann appears of interest in conjunction with the question of the effectiveness of the oxide phase in preventing grain growth.[8] Diffusion and electrical conductivity measurements indicated that the oxygen in SAP may not be found in the form of pure Al_2O_3, but in a non-stoichiometric oxide with excess aluminum. The investigators also found that diffusion takes place in pure sintered Al_2O_3 at the 500° to 550°C (930° to 1020°F) temperature level, but that it is *of a much lower order* of magnitude than that observed in SAP.

History of alloy development

Powder metallurgy forms the basis for the dispersion strengthened products of aluminum and other light metals. Experience with mechanical and chemical methods of producing these metals in fine particulate form, and general knowledge of consolidating masses of these comminuted metals through heat treating and hot working, served as background for the light metal dispersion-alloy development during the past two decades.

Reviews of the powder metallurgy of the light metals were published in 1948 and 1950.[22, 23] The earliest record of work in this area dates from 1909, when Masing reported an investigation of the formation of intermetallic compounds from mixtures of different metal powders with magnesium powder.[24] Thirteen years later, Sauerwald reported on ex-

periments with different types of aluminum powder.[25] In the light of our present knowledge of the beneficial role that oxygen can play in aluminum products, his observations and comments must strike us as rather curious indeed. Aluminum powders, irrespective of their method of production, invariably display oxide films of a certain thickness. This was alleged to have made pressing of the powder into compacts difficult, and also was said to have interfered with the capacity to sinter to such an extent that it was practically impossible to obtain a solid and coherent sintered body. Especially unsatisfactory strength properties were obtained with powders having leafy particles and large surfaces exposed to oxidation.[25] This viewpoint was considered a classic concept for over 20 years, and was in part still shared by Cremer and Cordiano in their 1943 report on research with aluminum and aluminum alloys produced from powders.[27]

These investigators made a special effort to combat abrasive and refractory properties of oxide films around the particles by the application of aluminum flake powder bearing die lubricants. The result of this investigation, however, gave for the first time an indication that aluminum powder metallurgy products with excellent engineering properties could be produced, a conclusion which was not so evident from the two preceding investigations by Kikuchi and Kempf.[25, 26] Cremer and Cordiano did not comment on the very high-strength properties which they obtained with simply pressed and air-sintered atomized aluminum powder blends (at 60 tsi compacting pressure they obtained a tensile strength of 17,500 psi and an elongation of 30 pct). It stands to reason that these properties are not due to the high compacting pressure employed, as sintering at 620°C (1148°F) must have fully annealed the cold-worked particles. Rather, it is likely that an oxide particle strengthening mechanism was operative similar to the one reported some 14 years later by Lenel and co-workers on work with atomized as well as flake powder products.[3]

It might be noteworthy that Bickerdike,[29] in 1947, still subscribed to the then prevailing school of thought that since the stable aluminum oxide films do not sinter noticeably except at temperatures higher than the melting point of aluminum, it would be necessary to bring metal surfaces free from oxide into contact with one another to make sintering of the particles possible. Bickerdike suggested two ways of doing this—either to prepare a powder substantially free from oxide by manipulations and pressing in an inert atmosphere, or by considerable distortion of the particles during compressing to effect rupturing of the surface films and metal-to-metal contacts. The powder used in his work was not tested for oxide content and no correlation between this constituent and the physical properties was attempted.

Forerunners of SAP and APM

Sauerwald's early concept of the deleterious effects of the oxide skins in sintered aluminum bodies was contradicted for the first time by Stern,[30] whose pioneering work in 1940 with the hot extrusion of pulverulent aluminum and magnesium scrap established a beneficial effect of the oxide films on the strength of the end products. This new trend was followed by Irmann and von Zeerleder, who greatly improved the end product by using much finer starting materials. Their efforts culminated in

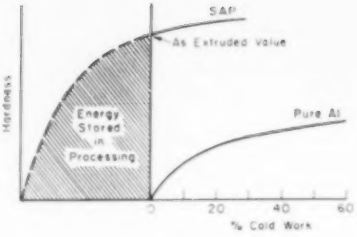

Fig. 4—Schematic representation of hardness changes with cold work in SAP and pure aluminum.[1]

the Sintered Aluminum Powder products (SAP). Patent applications were filed by the Aluminium Industrie AG in Switzerland in 1946.[31] Shortly thereafter, Lyle's development of the Aluminum Powder Metallurgy products (APM) was announced by the Aluminum Co. of America.[5] These contributions to powder metallurgy are of historic significance, as they ushered in the era of dispersion-strengthened alloy development.

Some six years prior to AIAG's first patent application, Stern [32, 33] experimented with the briquetting and consolidation of light metal scrap which included fine particulate substances obtained from turnings, borings, filings, and grindings. In a series of patents[32] (the first of which was filed in 1940) he disclosed a process which may be considered basic to the production of dispersion alloys in two respects: he used particulate aluminum- and magnesium-base substances characterized by oxide films, and he employed hot pressing, hot forging, and hot extrusion at temperatures up to 500°C (930°F) to effect rupturing of the films, metal-to-metal contact and, thus, fullest consolidation and densification. Even though his starting materials were coarse—the particles rarely being under 50μ in the major axis—quite remarkable physical properties were obtained.[34, 35]

Unalloyed 2-S produced by this process showed a room temperature yield point of 15,000 to 18,000 psi, a tensile strength of 26,000 psi, and an elongation of 12 to 19 pct. For unalloyed magnesium, tensile values reached 29,800 psi at an elongation of 8.5 pct. Even at a test temperature of 400°C (750°F), an extrusion of fine filings* of 2-S still

* 10-50μ thick, 15-65μ wide, 25-250μ long.

displayed tensile strength values reaching up to 6300 psi with corresponding elongation values of 22 pct. A cursory comparison with the mechanical properties of standard cast and wrought aluminum and magnesium[36] shows a two to threefold increase in strength at room temperature and a fourfold increase at 400°C (750°F).

Stern was apparently satisfied with the type of strengthening effects obtained on these coarse materials, being primarily interested in the consolidation aspect from the viewpoint of scrap processing without remelting. However, his disclosure (US Patent 2,391,752) of a structure of dispersed, uniformly distributed oxide in the aluminum bodies compressed from his pulverulent materials, when taken in conjunction with the type of properties observed, strongly implies that a slip-inhibiting process was operative. The fact that 1.09 to 1.45 pct oxide was determined analytically in his starting materials,[35] which generally were in the form of platelets or needles, seems to explain the high tensile values unattainable in standard 2-S without substantial work hardening. The fourfold increase

in the tensile strength at 400°C (750°F) over that of 2-S, places this material reasonably close to values for atomized powders on the oxide vs 400°C tensile strength curve established by Lenel,[8] Fig. 5.

Developments abroad

Several years later, Sauerwald followed a similar approach and confirmed some of Stern's findings.[37] Thus, Sauerwald apparently reconsidered his earlier position. In his new work he was primarily concerned with the economic re-processing of pulverulent scrap metal. Fine bandsaw cuttings of uniform particle size were used for consolidation without melting. By using hot-pressing and extrusion techniques, some remarkable properties could be developed. An aluminum alloy with 9 pct Mg extruded to an 8-mm diam rod, displayed the properties shown below. Figures on the right are for the cast and extruded alloy.

0.2 pct yield strength, psi	41,600	40,400
tensile strength, psi	62,500	58,500
elongation, pct	16.4	10.5

A magnesium alloy with 9 pct Al double extruded to a 3-mm diam rod had the following properties:

0.2 pct yield strength, psi	44,600
tensile strength, psi	50,000
elongation, pct	3.3

The cast and extruded alloy had a yield strength of only 32,300 psi, but an elongation of 11.5 pct. Although the difference in tensile strength was less pronounced than that of yield strength and ducility, it appears likely that a strengthening effect was obtained from the oxide phase introduced by surface films on the original particles. However, no firm conclusions can be drawn regarding the extent of dispersion vs solution strengthening, since Sauerwald did not report details concerning particle size, oxygen content, and impurities.

The contribution of the Swiss workers, a matter of record, was to utilize increasingly finer atomized and ultimately flaked aluminum powders with their concomitant oxide enrichment in the production of sintered products of exceptional strength and thermal stability. Since the first public announcement by von Zeerleder[38] and Irmann[39] in 1949, some 50 publications have described SAP, its properties, applications, details of the preparation of the powder, and its conversion into the wrought form. A recent paper by Irmann summarizes the latest data and applications, and lists most of the pertinent references.[40]

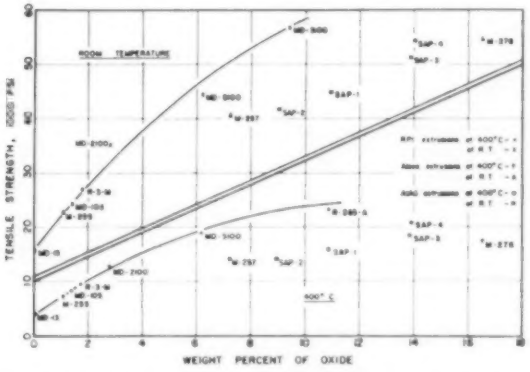

Fig. 5—Comparison between the tensile strength of experimental and commercial aluminum powder extrusions as a function of the oxide content.[10]

In Britain, Macdonald and Ransley reported on the development of dispersion strengthened aluminum alloys for the specific purpose of raising the modulus of elasticity.[41] Employing the powder metallurgy techniques of mixing atomized powder with the elemental powders (200-mesh size) of different intermetallic compounds, followed by either cold pressing, sintering and hot coining, or by hot pressing and extrusion, they produced alloys with dispersed phases of $MnAl_6$, $NiAl_3$, $CrAl_7$. It was possible to increase the modulus by 20 to 50 pct, if the volume proportion of the second phase was substantial. More effective was the addition as fine powder of the compound TiC over the range of 5 to 40 pct (3 to 27 vol pct). A 15 wt pct addition resulted in a modulus of the order of 13 x 10^6 psi.

Two methods of producing magnesium extrusions from distinctly different starting materials were found by Brown to lead to similarly high tensile strength properties.[42] One involved extrusion of flake-type powder resembling SAP (but coarser), the other was the direct extrusion of spherical particles produced by atomization of magnesium alloys. The yield and ultimate strength in tension values reached 35,000 and 45,000 psi, respectively, while elongation values ranged from 3.5 to 8 pct. The investigation did not cover the role of the oxide as a variable, but included a limited study of the co-extrusion of magnesium powder with up to 20 pct of a 50-50 Mg-Al master alloy powder.

US progress described

In this country, the development of dispersion-strengthened light metals took two courses. The Aluminum Co. of America, in its APM products, generally, followed the approach of the Aluminium Industrie AG. In 1952, Lyle[6] reported on the excellent tensile properties and creep and fatigue resistance which he obtained with two alloys in particular: M257 with about 7.8 pct oxide, and M276 with about 16.5 pct oxide. M257 was found to show superiority in strength over the best of the commercial wrought aluminum alloys at and above 260°C (500°F), and M276 was found to be even stronger, approaching the properties of SAP. Subsequent investigations by Gregory and Grant compared the properties of several APM alloys with SAP, and established extensive elevated temperature data.[4] They confirmed the thermal stability of these materials in stress-rupture tests and found that the strongest alloy, M276, closely approaches the curve for SAP at 205° and 315°C (400° and 600°F), while for 482°C (900°F) the difference was greater and the slope steeper, an indication of diminished thermal stability. Lenel and co-workers,[8] producing their own extrusions from a series of commercial flake powders, concentrated on establishing the relationship between particle size and flake thickness, and yield and tensile strength at ambient temperatures and at 400°C (750°F). Their results gave strong indications that the oxide content has only a minor effect on these properties—except as it depends upon the flake thickness—and that the degree of dispersion of the oxide phase appears to be the controlling factor.

The second approach followed in this country was first proposed by Busk and Leontis on magnesium in 1950.[10] Instead of consolidating fine flake powders, difficult to handle in the case of aluminum and virtually impossible to produce under industrially safe conditions in the case of magne-

sium, relatively coarse powders were produced by atomization. As a result of instantaneous freezing of the metal droplets through quenching with a cold gas, spherical particles were produced of the alloy AZ31 (3Al-1Zn-0.2Mn) which displayed a cast structure of finely distributed, highly cored dendrites. Extrusions from this powder had a finer grain structure and higher strength as compared to those from billets made by conventional practices. Heating of the powder prior to extrusion at 260°C (500°F) for 1 hr removes only some of the coring, and heating for 3 hr at 315°C (600°F) does not lower the extrusion properties. Heat treatment at 455°C (850°F) for 3 hr, however, sharply decreases the compressive yield strength of the extrusion. Busk and Leontis' interesting approach to produce fine dispersions of an insoluble intermetallic Al-Zr compound by precipitation after diffusion of the zirconium and aluminum from a compacted mixture of eutectic Mg-Zr and Mg-Al master alloy powders was mentioned above. Yield strengths of over 45,000 psi, and tensile strengths of over 50,000 psi were obtained with extrusions from alloys made in this manner. The work by the same investigators with Mg-6Al powder extrusions from machining chips closely follows the earlier work by Stern and by Sauerwald.

The use of atomized powders for dispersion alloys of aluminum was first discussed by Lyle in 1952.[5] Alloy M255 extrusions were produced from relatively coarse atomized powder containing no other constituents other than 0.5 pct oxide. Even this limited oxide phase and the likelihood of a poor dispersion caused by the type of powder used, raised the room-temperature yield and tensile strengths of the alloy to 17,600 psi and 22,600 psi, respectively, at an elongation of 22 pct. At 300°F (150°C), the alloy displayed a good combination of electrical conductivity and resistance to creep. At higher temperatures (400° and 600°F), Gregory and Grant found that the material displayed instabilities due possibly to grain growth or stress relief.[4]

Coarse, atomized, aluminum-alloy powders have also formed the basis for the more recent dispersion alloy developments by the Aluminum Co. of America.[7] Their thermal stability depends on a dispersion of $FeAl_3$ instead of Al_2O_3. A better combination of ductility and strength at room temperature and up to the 315° to 430°C (600° to 800°F) temperature range is a noteworthy improvement over the Al-Al_2O_3 alloys of medium oxide content. At 430°C (800°F), the strongest of these atomized powder alloys, M486, is comparable in strength to the flake product M257, but has four to five times the elongation (20 to 23 pct). The fact that these coarse-grained atomized powders are advantageous from the economic and industrial processing point of view, will undoubtedly encourage research into other aluminum-base dispersion hardenable alloy systems of this general type.

Editor's note—Next month, Dr. Goetzel will discuss the properties and applications of dispersion alloys.

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THE SENIOR CLASS:

Metallurgy and Metallurgical Engineering

by John P. Nielsen

AS a service to the metallurgical profession, AIME is embarking upon an annual publication of the list of seniors in metallurgy and metalurgical engineering throughout the various engineering and science schools in the US.

This initial tabulation includes 752 seniors from 56 schools, plus seniors from three schools that have no metallurgical curriculum as such, but that have some form of opportunity for metallurgical specialization in the undergraduate levels, e.g., a metallurgical senior thesis in a mechanical engineering curriculum with emphasis on metallurgical course electives.

The question of degree designation and type of curriculum is a complicated one. Indeed, the titles of departments conducting metallurgical programs vary, as shown in the following title tabulation ("department" or "school" is omitted). The number times each departmental title was found is indicated.

Metallurgical Engineering (20), Metallurgy (9), Mining and Metallurgy (9), Chemical and Metallurgical Engineering (5), Mineral Technology (2), Mineral Industries (2), Mineral Engineering (2), Mining Engineering (2), Metallurgy and Materials Science (1), Chemical Engineering (1), Mining, Metallurgical, and Mineral Engineering (1), Mechanical Engineering (1), Mines (1).

Metallurgy and *metallurgical engineering* have somewhat different interpretations in different schools. The list of seniors below is intended to include only those specializing in extractive metallurgy, production of metals, applied metallurgy and physical metallurgy. There may be some who specialized in mineral dressing in extractive metallurgy curricula, and some in metal physics. At any rate, mining and geology seniors are not included, their names being intended for a corresponding list in MINING ENGINEERING.

There are schools such as Harvard, California Institute of Technology, and the University of Chicago, that have a metallurgical faculty but no metallurgy program for undergraduates. The emphasis may be only on graduate work or, in some cases, the metallurgy faculty may give metallurgy courses to engineering or science students only in other curricula. These schools have not been included.

The list originally was intended to have also indicated those seniors who plan to go to full time graduate work. Acquiring this information led to complications which could not be resolved in time for publication. It is hoped that in the future this information will be available.

JOHN P. NIELSEN is professor and chairman, Dept. of Metallurgy, New York University. Data for this article were obtained under the auspices of the AIME Student Chapter Affairs Committee, John C. Calhoun, Jr., E. H. Crabtree, Jr., and John P. Nielsen (Chairman).

(**Bold face** indicates AIME member.)

UNIVERSITY OF ALABAMA, University, Ala., Dept. of Metallurgical Engineering, Prof. E. C. Wright, Chm: (February 1959) C. R. Denaburg, E. G. Farrier, J. R. King. (June 1959) D. F. Bowers, J. A. Curley, J. B. Dilworth, H. E. Gilmore, W. M. House, M. Schatz, J. M. Seibert, P. W. Shin, A. E. Wynne. (August 1959) L. A. Bowers, C. A. Carter.

UNIVERSITY OF ALASKA, College, Alas., School of Mines, Earl H. Beistline, Dean: **C. McNeil.**

UNIVERSITY OF ARIZONA, Tucson, Ariz., College of Mines, Dept. of Mining and Metallurgical Engineering, Prof. J. D. Forrester, Act. Head: **E. D. Albrecht,** W. L. Autrey, G. A. Burns, **J. A. Caid,** D. E. Clawson, **R. D. Groves,** H. D. Harper, R. L. Johnson, **P. H. Kreyns,** T. B. Lund, R. J. McLean, **G. Saltzman, W. E. Seginski,** L. E. Thomas, W. T. Vomocil, **P. L. Wallace,** R. T. Zimmerman.

THE SENIOR CLASS

POLYTECHNIC INSTITUTE OF BROOKLYN, New York, N. Y., Dept. of Mechanical Engineering, Prof. Charles T. Oergel, Head: M. H. Fassler, R. C. Fink, S. Friedman, **I. B. Gregerman,** P. J. Hanley, Jr. **A. B. Imgram,** R. E. Koondel, **R. I. Manberg,** R. R. Mastrangelo, M. Negrin, **S. Tager, E. Troc.**

UNIVERSITY OF CALIFORNIA, Berkeley, Calif., Dept. of Mineral Technology, Prof. Joseph A. Pask, Chm: W. L. Barmore, J. V. Brandewie, **Y. Chung,** J. J. Holmes, M. H. Kuperman, S. M. Myron, R. E. Nichals, E. M. Smith.

CARNEGIE INSTITUTE OF TECHNOLOGY, Pittsburgh, Dept. of Metallurgical Engineering, Prof. Robert F. Mehl, Head: C. L. Beck, J. E. Bennett, J. Berkenkamp, Mary L. Brady, J. M. Clayton, H. W. Cummings, E. Fortner, F. J. Fraikor, R. W. Goetz, A. F. Graziano, J. D. Hall, F S. Larson, Jr., D. MacFarlane, J. P. Martin, J. W. Mehalko, G. A. Niethamer, G. Schoenberger, R. R. Sillman, H. H. Swisher, J. A. Valley, R. D. Werner, D. E. Zakman, D. C. Zimmerman.

CASE INSTITUTE OF TECHNOLOGY, Cleveland, Dept. of Metallurgical Engineering, Prof. Albert R. Troiano, Chm: **R. L. Barto,** R. J. Botsco, **L. A. Brough,** M. A. Ciomek, J. N. Cordea, **M. J. Deitsch,** N. F. Donaghy, **R. G. Donnelly,** E. C. Dremann, R. C. Garver, T. E. Hale, F. J. Hauser, **C. C. Koch,** J. R. Konecsni, R. G. Leddon, **P. A. Lidrbauch,** R. F. Manzell, R. E. McCracken, **J. L. Mihelich, J. M. Palsulich, T. A. Patronite,** T. S. Piwonka, E. L. Raymond, C. F. Ruhl, A. G. Sage, P. L. Stone, J. W. Thornhill, J. S. Viland, R. R. Wiegel, R. A. Wullaert.

UNIVERSITY OF CINCINNATI, Cincinnati, Dept. of Chemical and Metallurgical Engineering, Prof. William Licht, Head: K. Banke, V. Beuhring, R. Bieber, R. Davies, R. Duerigen, J. Eckhart, G. Fisher, G. Gelazela, M. Hider, M. McComas, R. McDaniel, R. Schardt, C. Schmidt, W. Stitzel, R. White.

COLORADO SCHOOL OF MINES, Golden, Colo., Dept. of Metallurgical Engineering, Prof. H. Gordon Poole, Head: G. J. Bagan, **R. E. Blom,** G. E. Brant, G. N. Brown, R. E. Brustkern, **L. G. Cahill, W. S. Case,** R. H. Cox, D. J. Dunn, A. G. Fernandez, R. C. Gerhardt, F. A. Greenberg, C. J. Guntner, C. H. Hamilton, R. W. Haskell, P. J. Herbert, D. R. Hiatt, J. R. Hiller, **R. N. Johnson,** A. E. Kampbell, V. Kerlins, K. Kono, **G. N. Krauss,** S. K. Kyriakides, W. N. Lawless, G. Lawrence, B. G. LeFevre, R. W. MacDonald, C. S. Martenson, C. S. Miller, D. W. Morse, O. A. Nesland, **D. B. Newton,** K. E. Nielsen, **H. L. Piper,** G. S. Plews, R. D. Resh, K. G. Robertson, J. M. Rushing, **K. C. Russell, P. Shaw,** R. C. Schutz, W. M. Scott, E. R. Shackleford, **J. D. Shambach, D. L. Smith,** R. K. Spears, T. P. Teenor, M. T. Thein, **L. I. Thomas,** R. L. Wells, V. H. Winchell.

COLUMBIA UNIVERSITY, New York, N.Y., Dept. of Mining, Metallurgical, and Mineral Engineering, Prof. M. D. Hassialis, Chm: E. M. Aqua, D. Jugle, R. L. Patterson, S. Rabinowitz, E. M. Symes.

CORNELL UNIVERSITY, Ithaca, N. Y., School of Chemical and Metallurgical Engineering, Prof. C. C. Winding, Dir: B. F. Croasdale, **R. C. Goodspeed, R. W. Hendricks, F. Hyman, O. K. Jenkins, F. G. Jones, N. B. Schmidt,** E. M. Yates, C. Y. Yoh.

DREXEL INSTITUTE OF TECHNOLOGY, Philadelphia, Dept. of Metallurgical Engineering, Prof. A. W. Grosvenor, Head: D. J. Caballero, W. H. Feilbach, J. J. Junod, P. J. Lare, J. E. Moore, M. Raefsky, A. H. Rosenstein, M. Thomas, R. F. Zierow.

UNIVERSITY OF IDAHO, Moscow, Idaho, College of Mines, Dept. of Mining and Metallurgy, Prof. Joseph Newton, Head: V. T. Archbold, D. W. Duggan, C. H. Hogberg, D. W. Lawton, **M. B. Shirts,** J. F. Van Epps.

UNIVERSITY OF ILLINOIS, Urbana, Ill., Dept. of Mining and Metallurgical Engineering, Prof. Thomas A. Read, Chm: D. Albright, **K. S. Brown,** W. Brzegowy, G. J. Canfield, C. R. Casey, T. Dreyer, J. D. Fortier, I. Freimanis, J. R. Gaebe, G. R. Goetsch, L. E. Hayes, D. R. Hise, **E. M. Horak,** M. Hyman, K. Janowski, A. Kerstein, B. G. Koepke, A. I. Lewis, R. E. Luetje, F. J. Majeske, M. D. Meyer, L. C. Michels, G. A. Morris, R. R. Morris, D. R. Neruda, H. J. Oberle, F. G. Smith, R. W. Stusrud, R. Weinberg, R. M. Willard.

ILLINOIS INSTITUTE OF TECHNOLOGY, Chicago, Dept. of Metallurgical Engineering., Prof. L. F. Mondolfo, Chm: D. C. Christianer, **F. W. Gotschall,** A. Heckler, **E. J. Kluth,** C. H. Lumpp, V. Lutka, J. L. Lytell, **J. B. Moran,** M. L. Preban, C. J. Reichel, **W. Warke,** H. Wheaton.

UNIVERSITY OF KANSAS, Lawrence, Kan., Dept. of Mining and Metallurgical Engineering, Prof. K. E. Rose, Chm: J. R. Bennett, **M. K. Bernitz,** R. S. Diaz, **C. C. Fatino,** R. E. MacDougall, L. D. Parsons, G. D. Richardson, J. S. Risbeck, K. B. Yeo.

UNIVERSITY OF KENTUCKY, Lexington, Ky., College of Engineering, Dept. of Mining and Metallurgical Engineering, Prof. Richard S. Mateer, Head: **F. W. Bennett, C. Brown,** W. J. Coy, B. A. Ewing, W. C. Setzer, R. J. Writt, W. M. Thomas, T. W. Reid, L. B. Claxton.

LAFAYETTE COLLEGE, Easton, Pa., Dept. of Metallurgical Engineering, Prof. Leon J. McGeady, Head: R. D. Cole, J. F. Emig, A. L. Forrest, R. W. Hinton, W. R. Hogan, W. R. Pickwell, Jr., V. J. Rivetti, W. D. Shuttleworth, C. R. Sutphen, Jr., D. A. Vasiliades.

LEHIGH UNIVERSITY, Bethlehem, Pa., Dept. of Metallurgical Engineering, Prof. Robert D. Stout, Head: W. G. Beattie, D. S. Campbell, J. G. Early, P. S. Ferrentino, L. M. Harbold, F. L. Homsher, P. J. Horvath, C. Interrante, M. T. Latanision, J. R. Lawrence, C. J. Long, H. W. McCurdy, S. L. Morse, J. R. Oberholtzer, J. B. Pearson, **P. P. Podgursky,** W. Richardson, J. M. St. Clair, W. E. Smith, W. Stolnacker, D. P. Tanzman, L. R. Tremblay, R. H. Vaughn, A. C. Zinck.

THE SENIOR CLASS

UNIVERSITY OF MARYLAND, College Park, Md., College of Engineering, Metallurgy Program, Prof. William A. Pennington, Head: S. C. Manaktala, F. M. Marx, W. E. Nuttall, T. R. Shives, H. Yakowitz.

UNIVERSITY OF MASSACHUSETTS, Amherst, Mass., Materials and Metallurgical Engineering, Prof. Carl A. Keyser, in charge: R. Mack, R. Taylor. (Senior thesis in metallurgy, degree designation in another field.)

MASSACHUSETTS INSTITUTE OF TECHNOLOGY, Cambridge, Mass. Dept. of Metallurgy, Prof. John Chipman, Head: D. H. Avery, M. R. Birnby, P. Brigham, A. S. Bufferd, G. Y. Chin, **W. P. Clancy,** A. J. Collins, **O. F. Devereux,** W. H. Goodnow, O. G. Haselton, G. T. Haymaker, **H. R. Heideklang,** J. Ingraham, R. J. Keene, H. P. Kempe, W. C. Kohlbrenner, K. G. Kreider, R. H. Krock, R. A. Kurtz, G. Langford, W. S. Latimer, **B. S. Levy, D. J. McGinty,** T. F. McKinney, E. D. Montrone, C. H. Neu, Jr., **H. J. Oberson,** R. L. Pober, D. A. Polak, **C. Prieto,** C. A. Rowe, E. M. Safran, I. M. Schmidt, **B. S. Shabel, S. Spooner,** C. O. Staples, K. C. Taber, R. E. Travis, P. F. Weihrauch, P. D. Weiser, J. Y. Wishart, P. Wong, W. L. Worrell.

UNIVERSITY OF MICHIGAN, Ann Arbor, Mich., Dept. of Chemical and Metallurgical Engineering, Prof. Donald L. Katz, Chm: J. D. Bitzner, R. K. Bowen, C. E. Coffey, J. M. Dahl, A. M. Dalati, E. A. Frutig, W. H. Herrnstein, III, G. M. Kerzner, S. Kostman, F. N. Markva, C. R. Mielke, Y. E. Smith, J. W. Smythe.

MICHIGAN MINING AND TECHNOLOGY, Houghton, Mich., Dept. of Metallurgical Engineering, Prof. C. T. Eddy, Chm: R. L. Beauchamp, D. T. Bullones, J. A. DeVore, R. G. Donoghue, R. W. Ehrlich, B. H. Gildersleeve, L. C. Graham, D. A. Heidt, C. W. Hewitt, L. G. Jamar, J. M. Kazaroff, V. A. King, Jr., H. R. Klievoneit, J. J. Kraus, G. H. Lawry, E. A. Lilley, T. E. Lippart, C. P. Johnson, L. M. MacDougall, D. J. McMillin, J. A. Martis, D. E. Mikkola, G. J. Petersen, **G. J. Scott,** G. W. Shannette, T. K. Sheldon, M. L. Shepard, D. W. Smith, G. K. Stearns, D. T. Switzer, G. L. Tabraham, J. P. Torreano, J. H. Wainwright, L. K. Wdowiak, W. J. Woodruff, G. W. Worth, E. M. Yedinak. Mineral Dressing: **P. D. Chamberlin,** G. R. Guiliani, J. M. Gregory, P. S. Hurd, R. H. Johnson, R. G. Klumb, **J. C. Nigro, T. N. Rushton,** D.M. Thayer.

MICHIGAN STATE UNIVERSITY, E. Lansing, Mich., Dept. of Metallurgical Engineering, Prof. A. J. Smith, Chm: J. C. Bierlein, H. L. Murphy, F. B. Slovinski, R. Williams.

UNIVERSITY OF MINNESOTA, Minneapolis, Minn., School of Chemistry, Dept. of Metallurgy, Prof. Morris E. Nicholson, Head, and School of Mines and Metallurgy, Prof. Strathmore E. B. Cooke, Head: B. E. Jacobson, J. F. Knudsen, W. T. Whitfield.

MISSOURI SCHOOL OF MINES AND METALLURGY, Rolla, Mo., Dept. of Metallurgical Engineering, Prof. A. W. Schlecten, Chm: (January 1959) D. W. Agers, A. F. Ahrens, Jr., F. E. Carstens, **W. F. Dennison,** R. C. Fabiniak, T. J. Fabiniak, C. R. Graf, M. E. Horton, F. B. Houska, E. A. I. Urrutia, R. A. Kibler, E. A. Kucharski, D. D. Madigan, J. V. Marler, M. W. Meyer, **L. A. Neumeier,** M. P. W. Overall, L. L. Sluzalis. (June & August) **J. G. Basden,** F. M. Berg, T. R. Colandrea, D. A. Dallmer, R. O. Dean, R. W. Denise, D. C. Ford, **K. A. Fowler,** R. K. Garrett, C. G. Grady, D. W Harris, R. Herchenroeder, P. R. Johnson, R. W. Jones, R. R. Krom, **N. L. Lawson,** M. W. Loket, **M. F. Marchbanks,** J. L. Nagy, L. L. Nelson, **D. J. Padberg, D. R. Parille,** S. H. Pru, J. L. Range, J. L. Ratliff, R. H. Rath, **M. O. Roberts,** G. R. Schevers, R. Schierding, E. R. Schmidt, W. Schwenk, H. H. Smith, E. T. Stark, R. C. Sun, R. J. Urban, W. J. Varga, C. A. Washburn, **S. Waxman,** E. B. Williams.

MONTANA SCHOOL OF MINES, Butte, Mont., Dept. of Metallurgy, Prof. C. W. Haynes, Head: **G. D. Alexander,** C. Bates, **D. S. Malyevac,** G. M. Maxwell, C. A. Plate, **R. W. Roberts,** J. Yopps. Mineral Dressing Option: J. P. Dreyer, **W. H. Painter, A. R. Rule,** Z. Zeising, **D. E. Zipperian.**

UNIVERSITY OF NEVADA, Reno, Mackay School of Mines, Dept. of Metallurgy, Prof. J. S. Winston, Chm: R. W. Adams, B. D. Jones, **D. R. Mathews.**

NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY, Socorro, N. M., Dept. of Mining and Metallurgy, Prof. Alvin J. Thompson, Head: L. V. Clark, **R. J. Imprescia, R. C. Ivanecky,** D. J. Nelson, D. E. Thompson, B. R. Tippin.

NEW YORK UNIVERSITY, New York, N. Y., Dept. of Metallurgical Engineering, Prof. John P. Nielsen, Chm: C. Anderson, B. Blazer, D. Dreiblatt, **H. Ezrol, G. Geschwind, M. Silver.**

NORTH CAROLINA STATE COLLEGE, Raleigh, N. C., Dept. of Mineral Industries, Prof. W. W. Austin, Head: R. L. Barnhardt, R. E. Burgess, R. G. Hardy, W. K. Hardy, W. C. Remini, F. M. Scott, O. Skiredj, J. M. Waller, B. R. Ward.

UNIVERSITY OF NORTH DAKOTA, Grand Forks, N. D., Dept. of Mining Engineering, Prof. A. W. Koth, Head: None reported for 1959.

NORTHWESTERN UNIVERSITY, Evanston, Ill., Dept. of Metallurgy and Materials Science, Prof. Morris E. Fine, Chm: J. Hadley, J. Powell, J. Wilkins, E. P. Dahlberg, F. D. Meyers, L. Schwartz. (Senior thesis in metallurgy, degree designation in another field.)

UNIVERSITY OF NOTRE DAME, South Bend, Ind., Dept. of Metallurgy, Prof. E. A. Peretti, Chm: J. Donovan, J. R. Feller, B. C. Jennings, J. Kacsits, R. J. Mandile, J. R. Marshall, R. D. McGowan, R. P. O'Shea, D. W. Readey, D. Scherpereel.

OHIO STATE UNIVERSITY, Columbus, Dept. of Metallurgical Engineering, Prof. Mars G. Fontona, Chm: K. Davis, R. W. Dolan, C. E. Ginn, E. J. Grandy, R. L. Hilgert, D. W. Hoffman, R. L. Kennard, R. J. Kirby, H. A. Matlin, R. Morgan, W. B. Noll, **E. C. Phillips,** J. L. Seng, C. D. Vessele, R. C. Zelle.

THE SENIOR CLASS

THE UNIVERSITY OF OKLAHOMA, Norman, Okla., School of Metallurgical Engineering, Prof. W. R. Upthegrove, Chm: K. J. Davis, D. R. Johnston.

UNIVERSITY OF PENNSYLVANIA, Philadelphia, School of Metallurgical Engineering, Prof. Robert Maddin, Dir: **F. R. Early, E. E. Gruber, Jr.,** J. P. Nundy, C. M. Shine.

THE PENNSYLVANIA STATE UNIVERSITY, University Park, Pa., College of Mineral Industries, Dept. of Metallurgy, Prof. Amos J. Shaler, Head: J. W. Andrews, R. S. Bartocci, P. W. Berenbrok, J. C. Brown, R. L. Caton, C. N. Freed, M. G. Glaz, Jr., R. D. Gray, M. W. Helwig, Jr., A. S. Jordan, **J. F. Lynch,** L. P. Myers, W. A. Nystrom, J. C. Seastone, E. B. Shelly, G. J. Spaeder, E. C. Strable, C. L. Thompson, Jr.

UNIVERSITY OF PITTSBURGH, Pittsburgh, Dept. of Metallurgical Engineering, Prof. J. A. Berger, Chm: A. Aromatorio, R. Bachowski, E. E. Bishop, A. J. Denne, A. J. Greco, J. E. Guthrie, J. F. Held, F. S. Lewkowicz, Jr., J. H. Liberman, **D. C. Reymond, R. C. Royle.**

PURDUE UNIVERSITY, Lafayette, Ind. Dept. of Metallurgical Engineering, Prof. Reinhardt Schumann, Jr., Chm: E. N. Armit, C. R. Bieber, T. V. Ciukaj, **J. D. Clyne,** R. W. Cook, P. F. Coyle, **W. A. Farrington,** R. L. French, R. W. Gass, **T. A. Gorecki,** D. A. Halterman, **S. J. Hruska, R. G. Johnson,** W. R. Johnson, **G. E. Kleinedler,** L. R. Krol, **E. A. Lauchner,** W. Lewellyn, **R. C. McAllister,** R. T. McAllum, **E. Meieran, J. M. Morrison,** R. Rucoba, L. F. Schulmeister, **R. L. Sharkitt,** W. Shropshire, F. A. Sianta, R. S. Stenberg, **E. A. Tellefsen, J. T. Venard, H. M. Wolfe,** L. Wolfson, **J. B. Young, Jr.**

RENSSELAER POLYTECHNIC INSTITUTE, Troy, N. Y., Dept. of Metallurgical Engineering, Prof. Arthur A. Burr, Head: L. W. Baum, Jr., L. M. Blanke, Jr., W. P. Blankenship, D. N. Braski, S. W. Carter, R. Chait, G. J. Dormer, R. F. Hyserman, P. A. Kammer, D. A. Karlyn, M. B. Klein, J. J. Koziol, R. A. Laferriere, E. N. Levine, L. E. Lubin, G. A. Lustig, H. MacLaren, Jr., C. R. Mackey, P. R. Makowski, M. A. Marciano, Jr., K. F. Mead, G. E. Meyer, Jr., B. M. Nielsen, W. D. Padian, A. A. Retzky, S. R. Rothstein, M. J. Salkind, D. E. Smith, J. N. Subero, D. P. Susman, F. E. Thompson, M. W. Thunberg, Jr., S. S. Wong, A. T. Wynne.

SOUTH DAKOTA SCHOOL OF MINES AND TECHNOLOGY, Rapid City, S. D., Dept. of Metallurgy, Prof. Paul H. Anderson, Head: J. A. Cristensen, V. G. Eschen, V. R. Friebel, **D. O. Gustad,** W. R. Hinken, **A. G. Hins, R. L. Hollenbeck,** R. D. Howe, **R. R. Maki, J. W. Matousek,** W. McCormick, R. J. Mehle, F. C. Sexton, **C. Sterkel.**

STANFORD UNIVERSITY, Stanford, Calif., Dept. of Metallurgical Engineering, Prof. O. Cutler Shepard, Head: R. Austin, W. D. Baker, T. W. Barbee, D. C. Bullington, T. M. Coulter.

STEVENS INSTITUTE OF TECHNOLOGY, Hoboken, N. J., Dept. of Metallurgy, Prof. Alfred Bornemann, Chm: M. Cababe, J. Casey, P. Cesario, H. Comprelli, J. DiMeo, R. Frahm, R. Grote, R. Laurence, H. Michaels, D. Romlein, F. Sachs, R. Sedlatschek, D. Skitt, M. Tschoke, L. Veprek, W. West, D. Weyant, E. Wylie. (Senior thesis in metallurgy, degree in another field.)

THE UNIVERSITY OF TENNESSEE, Knoxville, Tenn., Dept. of Chemical and Metallurgical Engineering, Prof. E. E. Stansbury, In Charge of Metallurgical Engineering: D. M. Hewette, H. G. Hopper, J. P. Plummer, W. F. Ragsdale, L. K. Walker.

TEXAS WESTERN COLLEGE, El Paso, Tex., Dept. of Mining and Metallurgy, Prof. J. C. Rintelen, Jr., Chm: **J. S. Armijo, R. E. Bardsley,** F. P. Battle, **W. M. Bilbo, D. R. Boyd, E. E. Chavez, B. L. Garner,** O. G. Loya, L. W. Harrington, **G. E. Krick, A. L. Lowenberg,** B. R. Lowry, **V. M. Macias,** G. P. Barkofcy, **F. A. Shunk.**

UNIVERSITY OF UTAH, Salt Lake City, Dept. of Metallurgical Engineering, Prof. Milton E. Wadsworth, Head: J. T. Coon, F. Crump, G. R. Dorny, R. S. Hope, C. Jelden, D. A. Reese, **L. A. Rogers,** J. R. Suazo.

VANDERBILT UNIVERSITY, Nashville, Tenn., Dept. of Metallurgical Engineering, Prof. W. P. Fishel, Chm: none for 1959.

VIRGINIA POLYTECHNIC INSTITUTE, Blacksburg, Va., Dept. of Metallurgical Engineering, Prof. John F. Eckel, Chm: E. Barton, Jr., R. H. Canada, C. W. Fox, L. A. Garcia, D. A. Mannas, R. Nichols, Jr., J. F. Povlich, III, J. H. Steele, Jr., C. F. Vaught.

UNIVERSITY OF WASHINGTON, Seattle, School of Mineral Engineering, Metallurgical Engineering div., Prof. Earl C. Roberts, Head: J. H. Adams, **L. Alcid,** D. A. Bolstad, F. E. Cooper, S. D. Dahlgren, A. E. Hall, **E. E. Hamal, D. W. Hood,** G. E. Miller, L. F. Nelson, P. F. Sands, J. D. Siddle, J. R. Wolfe, R. F. Wolter.

STATE COLLEGE OF WASHINGTON, Pullman, Wash., College of Engineering and Mineral Technology, Dept. of Metallurgy, J. P. Spielman, Dean: **W. L. Cunningham,** K. Davidson, C. F. Fetzer, **R. E. Hanneman,** G. D. Pittman, **D. Stiefbold.**

WAYNE STATE UNIVERSITY, Detroit, Dept. of Chemical and Metallurgical Engineering, Prof. H. G. Donnelly, Head: J. J. Angeliu, B. G. Calfin, **C. M. Casper, J. Gerulaitis, L. J. Kastura, C. W. Kovach, D. M. Kovach,** W. Letts, H. C. Rezeau, Jr., E. H. Sanders, A. E. Schneider, Jr., **R. Titran.**

WEST VIRGINIA UNIVERSITY, Morgantown, W. Va., Dept. of Chemical Engineering, Prof. W. A. Koehler, Head: No seniors this year.

UNIVERSITY OF WISCONSIN, Madison, Wisc., Dept. of Mining and Metallurgy, Prof. P. C. Rosenthal, Chm: (February 1959) R. C. Allen, T. Bosworth, W. S. Irvine, **R. G. Lundholm,** A. M. Meyers, R. C. Nichols, W. F. Shaw, J. R. Widmeyer. (June, 1959) J. E. Cantwell, **C. S. Cook, E. A. Kelzer, R. M. Morrison, A. C. Mueller,** D. G. Newby, **J. L. Selky,** J. E. Walderberger, **T. D. Watts,** R. L. Wilkey.

YALE UNIVERSITY, New Haven, Conn., Dept. of Metallurgy, Prof. W. D. Robertson, Chm: **D. P. Duff,** N. G. Error, Jr., G. H. Geiger, R. F. Karle, D. M. Maher.

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AIME

METALLURGICAL SOCIETY OF AIME

NEWS

MECHANICAL WORKING COMMITTEE HOLDS FIRST TECHNICAL CONFERENCE

The Iron and Steel Division's Mechanical Working Committee, recognizing the need for an independent Technical Conference, held symposiums in Chicago on *Factors Affecting Shape and Surface Texture of Hot and Cold Rolled Products* on the morning of January 21st, and on *Continuous Heat Treatment of Flat Rolled Products* in the afternoon. In spite of deep snowdrifts that grounded air travel and made driving hazardous, 223 registered for this initial meeting at the Del Prado Hotel.

Opening the one-day meeting was a panel discussion on *Surface Texture, Flat Rolled Products*. Participants were W. H. Rees, assistant manager, Wide Strip div., Great Lakes Steel Corp., Ecorse, Mich.; F. F. Aloi, metallurgical engineer, Bethlehem Steel Co., Bethlehem, Pa.; J. A. Ward, superintendent, Cold Reduction & Tin Mills, The Steel Company of Canada Ltd., Hamilton, Ont., Canada; S. Daily, general foreman, Finishing, No. 3 Cold Strip Mill, Inland Steel Co., Indiana Harbor, Ind.; Norman Henchman, assistant superintendent, Sheet and Tin div., U. S. Steel Corp., Gary, Ind.; and L. R. Schoenberger, strip mill metallurgist, Jones & Laughlin Steel Corp., Pittsburgh.

J. G. Sibakin, division metallurgist, Develoment and Special Duties div., The Steel Company of Canada Ltd., Hamilton, Ont., presented a paper, *Factors Affecting Strip Profile in a Hot Strip Mill*, coauthored by J. S. Ride and W. Sherwood. This was followed by a paper on *Influence of Hot Strip Profile on Subsequent Operations*, delivered by J. F. Griffen, and coauthored by G. R. Christoph, both with Metallurgical Operations, U. S. Steel Corp., Pittsburgh. Serving as Chairmen of the morning session were R. Schuler, manager, North Mills, Inland Steel Co., and Howard Kaeff, general superintendent, Flat Rolled div., Youngstown Sheet & Tube Co., Chicago.

The lead-off paper at the afternoon session, *Continuous Normalizing of Flat Rolled Products*, was presented by D. C. Osborne, assistant general superintendent, Armco Steel Corp., Middletown, Ohio. This was followed by a paper on *Continuous Annealing of Deep Drawing Sheet Steel* by D. J. Blickwede, division head, Physical Metallurgy, Bethlehem Steel Co., Bethlehem, Pa. Continuous annealing is applicable where: 1) economies are gained, as in galvanizing; 2) special properties are obtained, as with tinplate; or 3) better quality is obtained.

In his paper on *Continuous Coil Annealing*, Clare Tucker of Lee Wilson Engineering Co., Cleveland, considered theory and practice that has led to development of steel mill annealing coils. The three methods of transferring heat—radiation, convection, and conduction—were compared.

(Continued on page 200)

Discussions on Stress Corrosion Invited

Written discussion of the conference papers presented at the *Physical Metallurgy of Stress-Corrosion Fracture* conference in Pittsburgh from April 2nd to 3rd, has been invited by Samuel J. Rosenberg, research engineer, Aeronautical Structural Materials, National Bureau of Standards, Washington 25, D. C. All discussions should be submitted in duplicate and mailed directly to Dr. Rosenberg.

Building Fund Pledged $1000 by Blast Furnace Committee

The Executive Board of the Blast Furnace, Coke Oven, and Raw Materials Committee has voted to pledge $1000 as a contribution to the Engineering Societies Building Fund for the year 1959. The Executive Board further resolved to examine its financial standing in 1960 and again in 1961, with the intention of subscribing $1000 each year to the Building Fund for the additional two-year period. The Blast Furnace Committee has accumulated a small fund for the successful operation of its annual conference, and from the sale of advertising in its *Proceedings*.

Nuclear Congress to be Held in April

The Fifth Nuclear Congress will hold its sessions in the Public Auditorium, in Cleveland, from April 5th to 10th. Thirty engineering, scientific, and management groups, co-ordinated through the Engineers Joint Council, will sponsor the Congres. The theme, *For Mankind's Progress*, will be carried out through 40 sessions, which will include discussions and papers on nuclear instruments, reactor component design, reactor instrumentation, nuclear fuel processing plants—design and practice, and reactor physics, as well as many others.

In addition, there will be an all-day session on Thursday, April 9th, which will be of special interest to metallurgists. The morning session, **Metallurgy & Materials** will feature the following papers:

The Fabrication of Tubular Uranium Fuel Elements, G. E. Polson, H. Davis, J. F. MacNeill, J. F. Schiltz, and J. Magoun, National Lead Co.

Fabrication of Urania Dispersed in Graphite Fuel Elements, J. H.

(Continued on page 201)

AROUND THE SECTIONS

St. Louis section heard a talk by Lawrence C. Widdoes, vice president, Inter-Nuclear Co., on atomic energy applications for mining and for power, at the January meeting. Low-grade ores, said Mr. Widdoes, could be crushed in place and then leached. It may be that fusion rather than fission-type explosives will be more applicable to mining since they produce less radioactive byproducts.

El Paso section announced the election of its officers for 1959 at the January meeting: chairman, Robert McGeorge; vice chairman, Eugene M. Thomas; secretary-treasurer, Guy E. Ingersoll; directors, A. A. Collins, Earl Donahue, J. E. Douglas, Louis Laurel, J. C. Rintelen, Jr., Ben D. Roberts.

Speaker of the evening was William P. Kilgore, vice president, El Paso Industrial Council Inc., who explained *What's Ahead in Labor Relations.*

Mohawk-Hudson section heard a talk by John Chipman, President-elect of The Metallurgical Society of AIME, at their January meeting held at Rensselaer Polytechnic Institute.

Washington, D. C. section announced their election returns at the Cosmos Club on January 6th. Chairman, Eugene D. Hardison; vice chairmen, Richard W. Smith, John Croston, J. T. Sherman; Council, Charles Merrill, W. F. Dietrich; secretary-treasurer, Albert E. Schreck; asst. secretary-treasurer, Alexander Garner.

The Section's 33rd Annual Oyster Party was held on February 3rd at the National Press Club. No formal speaker was scheduled.

Louis McCabe, outgoing Section chairman, talked on *Air Pollution in the Mineral Industries.*

Oregon section's new vice chairman S. L. Sampson, began the 1959 program with three movies on the atom at the January meeting. Chairman for this year is D. W. Johnson.

Reno subsection installed its new officers on January 9th at the Mapes Hotel. Hugh A. Shamberger, director, Nevada Dept. of Conservation, spoke on projects and organization of the Dept. of Conservation, with emphasis on development of water in northern Nevada.

Montana section held its first meeting of 1959 at the Montana School of Mines. *Crystal Gazing with X-rays* was the subject of guest speaker James K. Grunig's talk.

New York section heard Elmer W. Pehrson, former director of mineral economics activities, AIME, outline the importance to the free world of mushrooming Chinese and Soviet mineral and industrial production, at the Mining Club on January 22nd.

Lima, Peru section listened to a talk on *The National Hydroelectric Potential of Peru,* presented by George Grieve, dean of the mechanical and electrical faculty at the National University of Peru. The meeting was held at the Hotel Bolivar on January 21st.

Utah section met at the Newhouse Hotel in Salt Lake City on January 15th to hear Harold Wright, executive vice president, The Galigher Co., discuss *Rubber and Plastics as Cost Savers in Metallurgical Installations.* Section chairman, Glen Burt, announced the officers and committees chosen for the ensuing year.

Atomic Mechanisms of Fracture Meeting Planned for April

The National Academy of Sciences, with the joint sponsorship of the National Science Foundation, the Office of Naval Research, and the Air Force Office of Scientific Research, has arranged a seminar on the *Atomic Mechanisms of Fracture,* to be held at the New Ocean House, Swampscott, Mass., from April 12th to 14th. Central theme of the conference is an understanding of the basic atomic mechanisms by which fracture occurs in metals, ceramics, and polymers; emphasis will be placed on fundamental studies of the basic mechanisms involved in cleavage, ductile, fatigue, and high-temperature fractures.

The program will consist of a series of invited papers which will be preprinted. Written and oral discussion will be welcome, and the papers and discussion will be published in book form.

Participants may register by writing to Prof. B. L. Averbach, chairman, or Dr. D. K. Felbeck, secretary, *Conference on Fracture, National Academy of Sciences, 2101 Constitution Ave., Washington 25, D. C.* Registration fee is five dollars.

Madrid Foundry Congress

The Instituto Del Hierro Y Del Acero will hold its 4th General Assembly and the 26th International Foundry Congress, in Madrid, on October 4th through 10th.

Mechanical Working Committee Conference

(Continued from page 199)

The last formal paper was given by J. E. Erhardt, market research engineer, Wean Engineering Co., Warren, Ohio, who described a novel process in the experimental stage, *Strip Annealing by Liquid Sodium.* By taking advantage of liquid sodium's unique property, high thermal conductivity, heating and cooling can be performed in liquid rather than in a gas. The afternoon session concluded with an open discussion on *Strip Cleanliness After Annealing.*

Chairmen of the afternoon symposium were S. Johnson, technical advisor. Tin Mills, Weirton, W. Va., and M. Edge, superintendent, Tin Mills, Tennessee Coal & Iron div., U. S. Steel Corp., Birmingham, Ala.

A pleasant interlude at mid-day was a luncheon-meeting, addressed by George F. Sullivan, Editor of *The Iron Age.* In speaking on *Russia Through a Reporter's Eyes,* Mr. Sullivan described impressions from his participating in a recent tour with the first industrial group from the United States to visit the Soviet Union. The speaker advised that the USSR is ahead of us in productivity from open-hearth and blast furnaces, but presently behind in electric furnaces and rolling mills. Current production of machine tools in the Soviet Union is 140,000 per year, compared to our figure of 35,000. The Soviet Union has picked up the best ideas from the West, and added to them.

Serving as welcoming speaker at the opening session and toastmaster of the luncheon, was Ralph D. Hindson, Chairman of the Mechanical Working Committee, and Assistant Chief Metallurgist, Steel Company of Canada Ltd., Hamilton, Ont. Sharing the spotlight were C. F. Schrader, superintendent, Metallurgical dept., Inland Steel Co., Vice Chairman of the Mechanical Working Committee, and chairman of the committee on Local Arrangements; and T. D. Hess, superintendent, No. 1 Open Hearth, Youngstown Sheet & Tube Co., East Chicago, Ind., co-chairman of the committee on Local Arrangements, and chairman of the host section of AIME. Responsible for registration, and newly elected to the post of Secretary-Treasurer of the Mechanical Working Committee, was Phillip H. Smith, director of purchasing, La Salle Steel Co. Chicago.

1959 Membership Directory

As a service to the members of The Metallurgical Society of AIME, a complete membership directory is to be included with the July issue of JOURNAL OF METALS. Probably, you have already received a card requesting information on your address and company affiliation. We ask you to fill out this card and return it to the New York office in order that you may be correctly listed in the 1959 Directory.

The July issue of JOURNAL OF PETROLEUM TECHNOLOGY, and MINING ENGINEERING will carry a membership directory of the Society of Petroleum Engineers and the Society of Mining Engineers, respectively.

Nuclear Congress

(Continued from page 199)

Handwerk, F. D. McCuaig, and C. H. Bean, Argonne National Lab.

Tensile Creep of Pure and Uranium-Loaded Graphites, L. Green, Jr., M. L. Stehsel, and C. E. Waller, Aerojet-General Corp.

The Use of Isostatic Pressure Techniques in the Fabrication of Fuel Elements, J. Fugardi and J. L. Zambrow, Sylvania-Corning Nuclear Corp.

Segration in Aluminum—13% Uranium Castings, D. Peckner, Westinghouse Electric Corp.

The Swelling of Irradiated U-Zr Alloy During Temperature Transients, W. V. Johnston, Knolls Atomic Power Lab.

The Effect of Metallic Impurities on the Properties of Uranium and 2 w/o Molybdenum-Uranium Alloys, J. M. Dickinson and E. E. Zukas, Los Alamos Scientific Lab.

In the afternoon session, **Metallurgy & Materials,** the following will be presented:

Sinterability of UO Powders for Fuel Elements, R. B. Wrinkle, Mallinckrodt Chemical Works.

Mechanism of Sintering of Ceramic Materials, R. Chang, Atomics International.

Forge Rolling Zircaloy Components, R. D. Johnson, Clevite Research Center.

Irradiation-Induced Hydrogen Absorption by Nickel-Enriched Zircaloy-2, W. Yeniscavich, R. A. Wolfe, and R. M. Lieberman, Westinghouse Electric Corp.

The Use of Ultrasonics in the Testing of Irradiated Fuel Elements, J. M. Fouts, General Electric—Hanford Labs.

The Development of Nuclear Radiation Resistant Fluids and Lubricants, W. L. R. Rice and Lt. D. A. Kirk, Wright Air Development Center.

Sodium Corrosion as a Function of Time, J. M. McKee, Nuclear Development Corp. of America.

Purification of Lithium by Vacuum Distillation, W. Arbiter and S. Lazerus, Nuclear Development Corp. of America.

New York Physical Metallurgists Meet in Brooklyn

The first 1959 meeting of the Physical Metallurgy group, New York section, AIME, convened at 2:30 pm on January 21st. Site of the gathering was the Polytechnic Institute of Brooklyn, where the Metallurgy Div. of the Mechanical Engineering Dept. was host to a group of area metallurgists.

Highlights of the visit were a tour of *Poly's* extensive laboratories, dinner in the school cafeteria, and a talk by Prof. B. D. Cullity, University of Notre Dame, on *Selective Control of Mechanical Properties by Control of Texture.*

The visitors were welcomed to the Institute by Prof. Charles T. Oergal, head of the Mechanical Engineering Dept. Following this, they embarked on an ambitious itinerary which included visits to the chemistry laboratories, aeronautical laboratories, X-ray and electron microscope facilities, design and dynamics laboratory, metallographic laboratories, the spectrographic laboratory, and metalworking laboratory facilities for melting, casting, forming, machine tool work, and powder metallurgy.

Prof. Cullity's talk described studies currently in progress at Notre Dame which may lead to a revision of current beliefs about the desirability and nature of textures or preferred orientation (used synonymously here). Results obtained to date indicate that cold working of metal may not necessarily always produce the same stable texture, and that variations in the nature of the deformation and other treatments may produce varying proportions of textures.

Prof. Cullity showed from experimental results that it might often be more advisable to investigate the possibility of exploiting the effect of texture on mechanical properties than to strive for elimination of texture (random orientation). Extensive discussion following the talk testified to the interest of the group in possibilities suggested by Cullity.

Credit for another well-organized meeting of the Physical Metallurgy group was shared by Prof. Otto H. Henry, Brooklyn Polytechnic Institute, and Chairman Sam Carapella, American Smelting & Refining Co.

Process Metallurgy Symposium to be Held in Pittsburgh

The preliminary program has been determined for the *International Symposium on the Physical Chemistry of Process Metallurgy*, scheduled from April 27th to May 1st at the Penn-Sheraton Hotel in Pittsburgh.

The Symposium will be sponsored by The Metallurgical Society of AIME and was organized by the Physical Chemistry of Steelmaking Committee of the ISD, the Physical Chemistry of Extractive Metallurgy Committee of the EMD, and the Melting and Casting Committee of the IMD. Pittsburgh section of AIME will act as host.

The entire year of 1959 is devoted to the bicentennial celebration of the founding of Pittsburgh. The Science committee of the Pittsburgh Bicentennial Association has generously made a grant to enable distinguished foreign scientists to attend the Symposium.

Dr. John F. Elliott, Dept. of Metallurgy, Massachusetts Institute of Technology, program chairman for the Symposium, has released details of the meeting, subject to revision prior to April 27th.

Registration cards will be mailed to all members of the EMD and ISD. Other AIME members, or non-members, who wish to register early for the meeting may obtain the necessary forms from the general chairman of the Symposium by writing to *Prof. C. L. McCabe, Dept. of Metallurgical Engineering, Carnegie Institute of Technology, Pittsburgh 13, Pa.*

Pre-registration fee for AIME members is $15.00; non-member fee is $25.00. Students will not be required to pay registration costs. Payment of the registration fee entitles the conferee to a bound copy of the proceedings of the Symposium, edited by Prof. George St. Pierre, Dept. of Metallurgy, Ohio State University.

The tentative program schedule appears below.

Monday, April 27, 1959

9:00-11:20 am

Session I—Physical Chemistry of Metallurgy Phases

Lecture: **The Physical Chemistry of Metals and Slag Solutions—Retrospect and Prospect:** F. D. Richardson, Imperial College, London, England.

Viscosity of Lime-Alumina-Silica Melts Between 1600° and 2100°C: P. Kozakevitch, IRSID, St. Germain-en-Laye, France.

Some Considerations on the Nature of the Surface of Silicon Melts: C. F. Cooper and L. C. McCabe,

(Continued on page 202)

Carnegie Institute of Technology, Pittsburgh, Pa.

Structure Analysis of Some Fused Salts and Oxides by X-ray Diffusion: S. Takeuchi and K. Furukawa, Tohoku University, Sendai, Japan.

11:30 am-12:20 pm—Special Lecture

Thermodynamic Properties of Iron-Blast Furnace Slags: John Chipman, Massachusetts Institute of Technology, and President, The Metallurgical Society of AIME.

2:00-5:00 pm

Session II—Physical Chemistry of Oxide Phases

Thermodynamics of Liquid Iron Silicates: J. Lumsden, Imperial Smelting Corp. Ltd., Avonmouth, England.

Some General Consideration on the State of Oxidation of Iron in Molten Silicates, Phosphates, and Silicophosphates: E. T. Turkdogan and P. M. Bills, British Iron and Steel Research Association, London, England.

Activity of Ferrous Oxide in the Stoichiometric FeO-SiO_2 System: C. Bodsworth and I. M. Davidson, University of Liverpool, Liverpool, England.

Statistico-Thermodynamical Studies on Fe-O System in the Molten State: S. Takeuchi and K. Furukawa, Tohoku University, Sendai, Japan.

Mixing of Silicates in Molten Slags: K. P. Abraham and F. D. Richardson, Imperial College, London, England.

Activities of Zinc Oxide and Ferrous Oxide in Liquid Silicate Slags: A. W. Richards and D. J. Thorne, Imperial Smelting Corp. Ltd., Avonmouth, England.

Structure of Surface Oxide Films on Molten Alloys: K. Niwa, G. Shimaoka, and I. Yamai, Hokkaido University, Sapporo, Japan.

2:00-5:00 pm

Session III—Thermodynamics of Metals

Measurement of Vapor Pressures at High Temperatures by the Transportation Method: C. B. Alcock and G. W. Hooper, Imperial College, London, England.

Vapor Pressures of the Liquid Metals, Copper, Silver, and Gold: P. Grieveson, G. W. Hooper, and C. B. Alcock, Imperial College, London, England.

Vapor Pressures of Lead-Antimony Alloys and the Atomicity of Antimony Vapor: A. W. Richards, Imperial Smelting Corp. Ltd., Avonmouth, England.

Activities of Carbon and Oxygen in Liquid Iron: S. Matoba and S. Ban-ya, Tohoku University, Sendai, Japan.

Activities of Aluminum in Binary Aluminum-Iron Alloys: P. Gross, D. L. Levi, E. W. Dewing, and G. L. Wilson, Fulmer Research Institute, Stoke Poges, Buckinghamshire, England.

Tuesday, April 28

9:00 am-12 m

Session IV—Nature and Structure of Liquid Metals

Structure of Alkali Metals in the Liquid State: L. Heaton, Argonne National Laboratories, Lemont, Ill.

Immiscibility of Liquid Metal Solutions: M. Shimoji, Hokkaido University, Sapporo, Japan.

Electrolysis and Diffusion in Liquid Alloys: P. C. Mangelsdorf, University of Chicago, Ill.

Theory of Electric Transport in Liquid Alloys: J. Angus, J. Verhoeven, and E. E. Hucke, University of Michigan, Ann Harbor, Mich.

Velocity of Sound on Liquid Lead-Tin Alloys: R. B. Gordon, Yale University, New Haven, Conn.

Activation Energy of Flow in Liquid Alloys: M. Shimoji, Hokkaido University, Sapporo, Japan.

2:00-5:00 pm

Session V—Transport and Mixing

Some Approaches to the Theory of Transport in Dense Media: S. A. Rice, University of Chicago, Chicago, Ill.

General Considerations of Diffusion in Melts of Metallurgical Interest: L. Yang and G. Derge, Carnegie Institute of Technology, Pittsburgh, Pa.

Diffusion of Some Alloying Elements in Liquid Iron: T. Saito, Y. Kawai, K. Maruya, and M. Maki, Tohoku University, Sendai, Japan.

Self-Diffusion of Iron and Copper in Molten Mattes: L. Yang, S. Kado, and G. Derge, Carnegie Institute of Technology, Pittsburgh, Pa.

Kinetics of Reactions Between Two Liquid Phases: L. Fister and T. B. King, Massachusetts Institute of Technology, Cambridge, Mass.

Observations on Liquid-Liquid Mass Transfer With Bubble Stirring: W. O. Philbrook and M. Veeraburus, Carnegie Institute of Technology, Pittsburgh, Pa.

2:00-5:00 pm

Session VI—Solubility and Phase Equilibria in Metal Systems

Determination of Solubilities in Liquid Metals: T. R. A. Davey, The Broken Hill Associated Smelters Pty., Ltd., Port Pirie, South Australia.

Use of Controlled Solidification in Polycomponent Phase Diagram and Ingot Segregation Studies: M. L. Hill and W. A. Tiller, Westinghouse Electric Corp., Pittsburgh, Pa.

Further Work on the Solubility of Nitrogen in Iron-Chromium Alloys: E. T. Turkdogan and S. Ignatowicz, British Iron and Steel Research Association, London, England.

Solubility and Rate of Diffusion of Nickel in Lead: J. L. Scott and H. W. Leavenworth, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Rates of Solution of Rotating Zinc Cylinders in Liquid Bismuth: J. K. Jackson and R. E. Grace, Purdue University, Lafayette, Ind.

Wednesday, April 29

9:00 am-12 m

Session VII—Process Reaction Rates and Mechanisms

Rates of Reduction of Some Iron Ores in a Fluidized Bed: H. H. Brant and W. E. Marshall, Armco Steel Corp., Middletown, Ohio.

Study of the Rate and Mechanism of the Hydrogen Reduction of Fine Hematite Ores: J. B. Henderson, The Broken Hill Proprietary Co. Ltd., Newcastle, New South Wales.

Kinetics of the Carbon-Oxygen Reaction in Liquid Iron: K. Niwa, M. Shimoji, T. Kishida, and Y. Itoh, Hokkaido University, Sapporo, Japan.

Kinetics and Mechanisms of the Conversion of Titanium Oxides to Titanium Nitride: D. L. Douglass, G. R. St. Pierre, and R. Speiser, Ohio State University, Columbus, Ohio.

Theory on the Reduction of Titanium Chloride by Metallic Sodium: T. H. Henrie and D. H. Baker, U. S. Bureau of Mines, Boulder City, Nev.

New Development of Titanium Production by Reaction in the Gaseous Phase: S. Takeuchi, M. Tezuka, T. Kurosawa, and S. Eda, Tohoku University, Sendai, Japan.

2:00-5:00 pm

Session VIII—Solidification of Metals

Instability of Solid-Liquid Interfaces: G. F. Bolling and W. A. Tiller, Westinghouse Electric Corp., Pittsburgh, Pa.

Degeneration of Freezing Plane Interfaces in a Controlled Solidification System: M. C. Flemings, H. F. Taylor, M. C. Adams, and E. E. Hucke, Massachusetts Institute of Technology, Cambridge, Mass.

Effect of an Electric Field on the Segregation of Solute Atoms at a Freezing Interface: J. Augus, D. V. Ragone, and E. E. Hucke, University of Michigan, Ann Arbor, Mich.

Grain Size Control During Ingot Solidification: W. A. Tiller, Westinghouse Electric Corp., Pittsburgh, Pa.

Crystallization of Spheroidal Graphite From Its Saturated Solutions in Liquid Iron Alloys: M. Olette and P. Kozekevitch, IRSID, St. Germain-en-Laye, France

Study of the Solidification Process in Chill-Cast Aluminum-Copper Ingots: W. V. Youdelis, University of Alberta, J. U. MacEwan, McGill University, and J. S. Kirkaldy, McMaster University, Canada.

2:00-5:15 pm

Session IX—Halides, Carbides, and Sulfides

Constitution of Cryolite and NaF-AlF_3 Melts: L. M. Foster and W. B. Frank, Aluminum Co. of America, New Kensington, Pa.

Heats of Formation of Cryolite and the Aluminum Fluorides: P. Gross, C. Hayman, and D. L. Levi, Fulmer Research Institute, Stoke Poges, Buckinghamshire, England.

Metal-Molten Salt Solutions, One-Phase Equilibria in the Systems Mg-$MgCl_2$ and Ca-CaF_2: P. S. Rogers, J. W. Tomlinson, and F. D. Richardson, Imperial College, London, England.

Studies of Equilibrium Between Metals and Their Polyvalent Chlorides in LiCl-KCl Eutectic Melt: L. Yang, R. G. Hudson, and Chien-Yeh Chien, Carnegie Institute of Technology, Pittsburgh, Pa.

Thermodynamic Properties of Zirconium Carbide: S. Fujishiro and N. A. Gokcen, University of Pennsylvania, Philadelphia, Pa.

Thermodynamic Studies of Pyrrhotite: K. Niwa and T. Wada, Hokkaido University, Sapporo, Japan.

Oxygen Content of Copper Mattes: M. Kameda and A. Yazawa, Tohoku University, Sendai, Japan.

8:00 pm

Principal Lecture: **Modern Concepts of Metallurgical Systems and Processes:** Henry Eyring, Dean of the Graduate School, University of Utah, Salt Lake City, Utah.

Thursday, April 30

9:00 am-12:15 pm

Session X—Industrial Application of Principles

Equilibria Between Lead, Lead Sulfide and Cuprous Sulfide and the Decopperizing of Lead With Sulfur: R. F. Blanks and G. M. Willis, University of Melbourne, Victoria, Australia.

Vacuum Distillation of Minor Elements From Liquid Ferrous Alloys: M. Olette, IRSID, St. Germain-en-Laye, France.

Physical and Chemical Relationships in the Iron Blast Furnace: J. F. Elliott, Massachusetts Institute of Technology, Cambridge, Mass.

Study of the Physical Chemistry of Titanium in the Blast Furnace: F. D. Delve, H. W. Meyer, and H. N. Lander, Jones & Laughlin Steel Corp., Pittsburgh, Pa.

Some Mechanisms in the Refining of Steels: B. M. Larsen and L. O. Sordahl, U. S. Steel Corp., Monroeville, Pa.

Analysis of Factors Affecting Temperature Drop Between Tapping and Teeming in Steelmaking: N. L. Samways, J. Halapatz, and T. E. Dancy, Jones & Laughlin Steel Corp., Pittsburgh, Pa.

Theoretical Aspects of the Pickle-Lag Phenomenon: W. G. Hines, The Steel Co. of Canada, Ltd., Hamilton, Ont., Canada.

9:00 am-12:15 pm

Session XI—Part I—Desulfurization in the Steel Plant

Sulfur Control in the Blast Furnace: J. G. Sibakin, J. McKay, and P. M. Audette, The Steel Co. of Canada, Ltd., Hamilton, Ont., Canada.

Effect of Applied Potential on Desulfurization of Iron and Steel: M. Ohtani and N. A. Gokcen, University of Pennsylvania, Philadelphia, Pa.

Factors Affecting Desulfurization and Dephosphorization in Basic Electric Steel Production: J. Zotos, Watertown Arsenal, Watertown, Mass.

Part II-Hydro- and Electrometallurgy.

Electrolytic Deposition of Tantalum From Fused Salt Systems: F. Kern and R. Bakish, CIBA Ltd., Basle, Switzerland.

Direct Leaching Zinc Sulfide Ore With H_2SO_4 and O_2 Under Pressure: F. A. Forward and H. Veltman, University of British Columbia and Sherritt Gordon Mines, Ltd., Canada, respectively.

Observations on the Kinetics of the Reduction of $NiSO_4$ and $CoSO_4$ in Aqueous Solutions: W. G. Courtney and F. A. Schaufelberger, Experiments, Inc., Richmond, Va., and CIBA Ltd., Basle, Switzerland, respectively.

2:00-3:45 pm

Session XII—Process Control and Statistical Methods

Contribution of Statistical Methods to Problems of Process Control: C. Daniel, Engineering Statistician, New York, N. Y.

A Technico-Economic Analysis of Stainless Steel Melting: R. W. Taylor, R. H. Gillespie, and D. C. Hilty, Union Carbide Metals Co., Div. of Union Carbide Corp., Niagara Falls, N. Y.

Mathematical Model for Sulfur Distribution in the Open Hearth: G. F. Lilly, U. S. Steel Corp., Monroeville, Pa.

4:00-5:15 pm

Summary of Conference and Direction of Research

Friday, May 1

Visits to Industrial Laboratories.

OBITUARIES

Roy E. O'Brien

An Appreciation By
Andrew Fletcher
and Henry DeWitt Smith

If we were to outline all the desirable qualities and background which a Field Secretary of the AIME should possess, we could find no finer example than the background and character of Roy E. O'Brien, who died in Salt Lake City on January 9, 1959. Born in the West, in Victoria, Colo. on July 3, 1898, he received an A.B. degree from the University of Colorado in 1923. He did not plunge immediately into mining but used his talents to sell Studebaker cars in Colorado. However, we imagine, coming from a mining family, mining was in his blood, for Roy next took a job as mine engineer for Cananes Consolidated Copper Co., in Mexico, and in turn became mine shift boss, division foreman, and assistant foreman. He then transferred his energies to the Mountain City Copper Co. remaining 13 years with the organization until 1949, ultimately becoming mine superintendent, and superintendent at Mountain City and Rio Tinto, Nev. His next change was to phosphate mining as general foreman of Anaconda's phosphate operations at Conda, Idaho. Unfortunately, however, a heart condition compelled him to relinquish his active mining career in 1950.

It was, therefore, AIME's good fortune to be able to appoint him Western Secretary of the Mining Branch on Sept. 1, 1950, with an office in Salt Lake City, and simultaneously, Assistant Secretary of the Institute. In 1953, the title of Western Secretary of the Mining Branch was changed to Field Secretary.

All of Roy's background stood him in good stead in his official capacity as Field Secretary. His friendliness, his understanding of the problems of the profession, his ability to get along famously with people, and his many dealings with the public, which are the lot of any mining manager, were qualities that served him and the Institute admirably. Hundreds of his friends throughout the country, and particularly in the western local sections of the AIME, will remember him with affection and as a valuable friend and counselor. They can attest to his warm personality and willingness to help make the AIME an indispensable organization for the profession.

Despite the handicap of a health which was none-too-robust, he injected his own love of mining and his devotion to the Institute into all of the areas in the West which he so ably served. One need only turn to the growth of western membership as ample proof of the successful discharge of his responsibilities.

His host of friends all over will miss his genial presence at AIME conventions and local affairs, and they will mourn the loss of one who has helped to maintain the high professional standing of the AIME so superbly. But they have one consolation. He has left behind his de-

voted wife, Lee, who is equally enthusiastic about mining and the ideals of the Institute. In fact, one cannot think of Roy and his work without thinking equally of the energy and devotion of Lee O'Brien for our Society.

Henry Krumb

An Appreciation By
H. DeWitt Smith

Henry Krumb, consulting mining engineer, died of cancer in New York City on Dec. 27, 1958 at the age of 83. As a youth he decided to become a consulting mining engineer and every step he took was with this goal definitely in view. His story is an inspiration to the engineering youth of this country, in whom he was vitally interested, and for whom he set up the *Henry Krumb Mining and Metallurgical Scholarship Fund* at Columbia University.

Henry Krumb was born in Brooklyn, N. Y., Nov. 15, 1875. He attended the Columbia University School of Mines, from which he graduated with the degree of Engineer of Mines in 1898.

After a year in New York City, first as draftsman and engineer and then as assayer and chemist, he went to British Columbia to look for a job more directly connected with mining, his chosen profession. He ran several small mines in the Rossland district, and in 1902 became chief engineer for the Camp Bird Mine in Colorado, under the general direction of John Hays Hammond.

In 1904 Mr. Krumb joined the engineering staff of the Guggenheim Exploration Co., as field engineer under Mr. Hammond, and during the next three years he examined and reported on gold, silver, copper, lead, and zinc mining properties in Alaska, Canada, Mexico, and various districts in the US. During this period Mr. Krumb began his connection with the so-called porphyry copper mines, the most important work of his career. He is universally credited among engineers with playing an important part in the successful development of the low-grade copper deposits which today yield about 60 pct of the world's copper.

In 1905 he examined the Utah Copper mine at Bingham, Utah, for the Guggenheim group. This examination required eight months' work, including extensive drilling to confirm the extent of the orebody, and large-scale treatment tests. As a result of Mr. Krumb's report, the Guggenheims furnished the funds with which shovel operations were started at the mine and a large concentrating plant erected at Garfield. This was the first porphyry mine to be exploited on a large scale and is today the largest copper mine in North America.

Immediately after the Utah Copper financing, Mr. Krumb examined other similar properties, including the Nevada Consolidated and Cumberland Ely, near Ely, Nev. A controlling interest in the Nevada properties was acquired by the Guggenheims as a result of Mr. Krumb's recommendations, a concentrator and smelter built at McGill, and a railroad built 140 miles to the main line of the Southern Pacific Railroad.

In the summer of 1906, Mr. Krumb headed an expedition to investigate the copper resources of the Copper River district in Alaska. As the result of these examinations, Kennecott Mines Co. was financed by the Guggenheims and J. P. Morgan & Co. to develop the mines and to build the Copper River and Northwestern Railroad.

In 1907, at the age of 32, Mr. Krumb established himself in private practice as consulting mining engineer, with offices in Salt Lake City, Utah. The next year he introduced the use of churn drills in the development of porphyry copper mines. Using this method, in the next two years he increased the developed ore reserves of Ray Consolidated and Gila River Co. in Arizona from 1,000,000 to 70,000,000 tons. At about the same time Mr. Krumb negotiated the purchase for William Boyce Thompson of the prospective porphyry properties of the Inspiration Copper Co., near Globe, Ariz. Mr. Thompson provided $11,000,000 for the development and equipment of these properties, and Mr. Krumb served as consulting engineer until 1912, during which time 45,000,000 tons of ore were developed.

Mr. Krumb in 1909 examined a prospect known as the Silver Queen, near Superior, Ariz., and on his favorable report, Mr. Thompson organized the Magma Copper Co. to acquire and develop it. Mr. Krumb served as consulting engineer for several years for this company, and later as a director.

Mr. Krumb's examination of Kennecott's Alaskan property in 1915 disclosed an orebody averaging 70 pct copper, the most phenomenal deposit of rich copper ore ever discovered. Mr. Krumb recommended that Kennecott use much of its great earnings from this high-grade but limited orebody in acquiring large low-grade ore reserves of the porphyry type, to assure long life to the company. Following his recommendation, Kennecott Copper Corp. was formed, the Alaskan mines and Copper River Railroad absorbed, the Braden Copper Co. in Chile merged and financed, and a large block of Kennecott shares exchanged for Utah Copper shares. Later, additional Utah Copper shares were obtained in exchange for Kennecott shares and by open market purchases. Ultimately all of Utah Copper and the Nevada Consolidated, Ray and Chino Co. were absorbed into the great Kennecott Copper Corp. as the result of discussions initiated by Mr. Krumb with Mr. Stephen Birch, president of Kennecott, on a hillside below Kennecott's Jumbo mine, one summer afternoon in 1915.

In 1916, Mr. Krumb went to South America to examine the Braden property, the Chuquicamata mine of Chile Copper Co., and the mines of Cerro de Pasco in Peru. During World War I, he was a member of the Priorities committee of the War Industries Board in Washington.

In 1920, Mr. Krumb examined the Flin Flon property in northern Manitoba for a group of which William Boyce Thompson, who later organized Newmont Mining Corp., was a member. The option was allowed to expire in the depression of 1921, but in 1928 Mr. Krumb was instrumental in obtaining a substantial holding in the property for certain of the clients for whom he made the original examination in 1920. Hudson Bay Mining & Smelting Co. Ltd. was organized and $24,000,000 spent on development and equipment of this property. Mr. Krumb had been a director and vice president of this company since its incorporation.

He was an active director of Newmont Mining Corp. from 1925 until his death, of O'okiep Copper Co. Ltd. from 1937, and of Newmont Oil Co. from 1939.

Henry Krumb became a member of AIME in 1905, and served as vice president from 1928 until 1942. His services to the Institute and to his profession through this period are summarized in the citation given him in 1939 when he was elected Honorary Member of the Institute "in recognition of his notable attainments as an engineer; of his constant and effective efforts in behalf of the profession, and his never-failing and wise counsel in the administration of Institute affairs during critical years."

In 1938 a donor, whose identity was disclosed only to the Treasurer of the AIME, established a specific fund designated as *Endowment Fund "X"*, with total gifts to principal of $96,912 over a period of ten years. The donor expressed the wish that the income from this fund be used preferably only in time of economic depression, so that the Institute would not be forced to curtail its activities when income from other sources dwindled. One objective of the donor was to show the soundness of investing in common stocks of well-operated mining and oil companies. This is borne out by the fact that the market value of this fund as of Dec. 31, 1958 was $860,272. After his death it was disclosed that Mr. Krumb was the

anonymous donor of Fund "X", henceforth to be known as the *Henry Krumb Endowment Fund.*

In 1939 he was awarded *The Egleston Medal* of Columbia University for distinguished engineering achievement. In 1951 he received the honorary degree of Doctor of Science from Columbia University, and in 1956 was awarded the Columbia *Class of 1889 Medal* for eminent achievement. He served on the board of trustees of Columbia University from 1941 to 1947.

Mr. Krumb had four major interests in his professional life—his career as a mining engineer, the advancement of the younger members of his profession, the AIME, and his alma mater, Columbia University. He had remarkable technical and financial acumen, a pleasing but forceful way in extracting basic facts, and a most retentive memory. His fund of knowledge and his definite views on business, finance, and politics, made him an equally welcome companion on the trail or across a directors' table. He was a great and very modest man. He mapped out his course of life and followed it to the end.

Mr. Krumb is survived by his wife, Mrs. LaVon Duddleson Krumb, to whom he was married in San Francisco in 1914.

Cecil H. Desch, (Member 1946, honorary member, Legion of Honor) passed away on June 19, 1958. Dr. Desch, a distinguished British scientist, started his career as a lecturer in metallurgical chemistry at Glasgow University. Following a succession of teaching positions, he became superintendent of the metallurgical department, National Physical Lab., in 1932. He held this post until 1939.

He was President of the Institute of Metals from 1938 to 1940; Vice President of the Institute of Sociology and the Iron and Steel Institute; and scientific advisor, Iron and Steel Industrial Research Council. At the time of his death, he resided in London.

Jesse A. Kingsbury, (Member 1937) died suddenly on Nov. 19, 1958. He was a senior metallurgical engineer at Metallurgical and Testing div., US Naval Gun Factory, Washington, D. C., since 1935. Prior to this, he was chief metallurgist at the Bendix Aviation Corp., South Bend, Ind. At the time of his death, Mr. Kingsbury resided in Springfield, Va.

Ralph C. McQuire, (Member 1939) died on Dec. 23, 1958, at Port Colborne, Ontario, Canada. Mr. McQuire joined The International Nickel Co. of Canada Ltd., in 1929 and was subsequently made manager of the Nickel Refining div. He was active in many organizations during his career, among them the AIME and the Association of Professional Engineers of Ontario.

NECROLOGY

Date Elected	Name	Date of Death
1944	Lawrence W. Allen	July 1958
1936	Leland C. Ball	June 23, 1958
1914	J. T. Boyd	Jan. 3, 1959
1946	Cecil H. Desch (Honorary Member)	June 19, 1958
1958	Albert R. Eckel	Dec. 4, 1958
1919	Dugald Gordon	Oct. 3, 1958
1885	H. L. Hollis (Legion of Honor)	Nov. 20, 1958
1928	H. O. Howard	Unknown
1915	L. R. Jenkins	Dec. 25, 1957
1913	Lee O. Kellogg	Dec. 2, 1958
1911	Joseph E. Kennedy	Jan. 9, 1959
1937	J. A. Kingsbury	Nov. 19, 1958
1905	Henry Krumb (Honorary Member) (Legion of Honor)	Dec. 27, 1958
1917	J. F. Linthicum	Nov. 17, 1958
1939	R. C. McQuire	Dec. 23, 1958
1919	Wendell Z. Miller	Mar. 11, 1958
1920	R. M. Overbeck	Sept. 23, 1958
1916	C. O. Stee	Dec. 28, 1958
1943	Charles E. Tonry	December 1958
1915	B. H. Van Der Linden	Oct. 5, 1958
1915	H. T. Walsh	Oct. 10, 1958
1895	Wm. Y. Westervelt (Legion of Honor)	Oct. 8, 1958
1926	B. L. Wheeler	Jan. 4, 1958
1935	Howard G. Wilcox	Sept. 9, 1958

MEMBERSHIP

Proposed for Membership Metallurgical Society of AIME

Total AIME membership on Nov. 1, 1958 was 30,815; in addition 3,279 Student members were enrolled.

ADMISSIONS COMMITTEE

J. H. Scaff, Chairman; Alfred Bornemann; F. B. Foley; T. D. Jones; L. L. Seigle; J. M. Warde; H. K. Work.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

Members

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Coming Events

Mar. 5. AIME, NOHC Cleveland Section, meeting, Rockside Gardens, Cleveland.

Mar. 11, AIME, NOHC, Chicago Local Section, All-day Off-The-Record Meeting, Del Prado Hotel, Chicago.

Mar. 12, AIME, NOHC Northern Ohio Local Section, Annual technical meeting, Pick-Ohio Hotel, Youngstown, Ohio.

Mar. 16-20, Western Metal Exposition and Congress, Pan-Pacific Auditorium, Los Angeles, Calif.

Apr. 2-3, AIME National Conference on Physical Metallurgy of Stress Corrosion Fracture, Mellon Institute, Pittsburgh, in cooperation with the Electrochemical Society, American Society for Testing Materials, and National Society of Corrosion Engineers.

Apr. 5-10, Fifth Nuclear Congress, Cleveland Auditorium, Cleveland.

Apr. 6-8, AIME 42nd National Open Hearth Steel Conference and Blast Furnace, Coke Oven, and Raw Materials Conference, Jefferson Hotel, St. Louis.

Apr. 16-18, AIME Northwest Regional Conference, Olympic Hotel, Seattle, Wash.

Apr. 22-26, Annual spring meeting of the Metal Treating Institute, Hollywood Beach Hotel, Hollywood, Florida.

Apr. 27-30, AIME International Symposium on the Physical Chemistry of Process Metallurgy, Penn-Sheraton Hotel, Pittsburgh.

May 4, AIME, NOHC Chicago Local Section, Spring meeting at Phil Smidt's Restaurant, Hammond, Ind.

May 14, NOHC Cleveland Section, meeting, Rockside Gardens, Cleveland. Topic: Basic Roofs.

May 21-22, AIME New England Regional Conference, Statler Hotel, Hartford, Conn.

June 5, AIME, NOHC Southern Ohio Section. Golf Outing, Summit Hills Country Club, Fort Mitchell, Kenton County, Ky.

June 13, NOHC Pittsburgh Section, Golf Party, Churchill Valley Country Club.

June 20, NOHC Cleveland Section, Dinner-Dance, Lake Shore Hotel, Cleveland.

Aug. 31-Sept. 2, Semiconductors Conference, Statler Hotel, Boston, Mass.

Oct. 16-17, NOHC Southern Ohio Section, Fall Meeting, Deshler-Hilton Hotel, Columbus, Ohio.

Nov. 2-6, Fall Meeting of The Metallurgical Society of AIME, Morrison Hotel, Chicago.

Nov. 6, NOHC Pittsburgh Section, Off-the-Record Meeting, Penn-Sheraton Hotel, Pittsburgh.

Dec. 2-4, AIME 17th Electric Furnace Steel Conference, Hotel Cleveland, Cleveland, Ohio.

Feb. 14-18, 1960, AIME Annual Meeting, Hotel McAlpin and Hotel Statler, New York.

Apr. 4-6, 1960, AIME 43rd National Open Hearth Steel Conference and Blast Furnace, Coke Oven, and Raw Materials Conference, Palmer House, Chicago.

June 13-15, 1960, first International Powder Metallurgy Conference, Hotel Biltmore, New York, under joint auspices of AIME and MPI.

Nov. 30-Dec. 2, 1960, 18th Electric Furnace Steel Conference, Morrison Hotel, Chicago.

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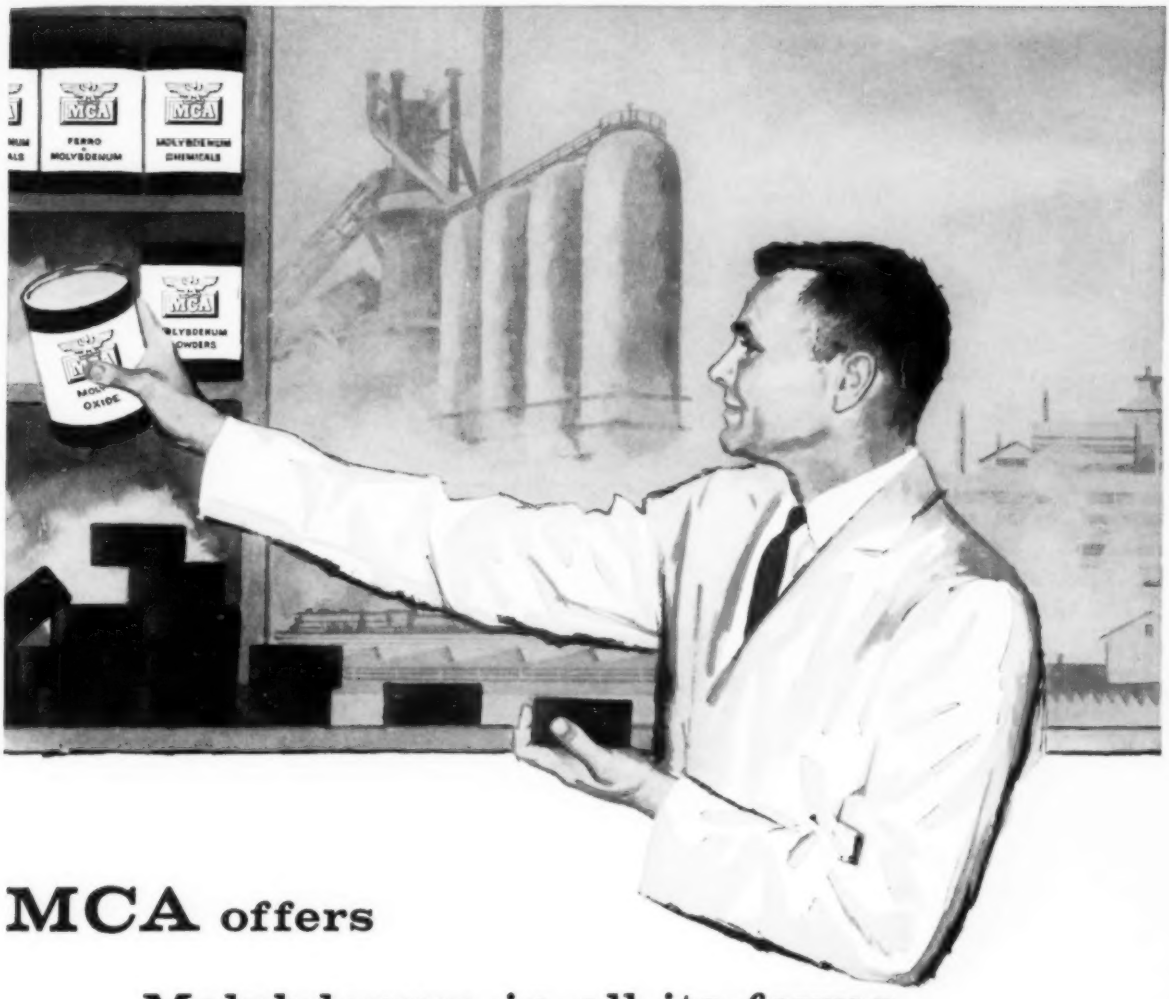

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